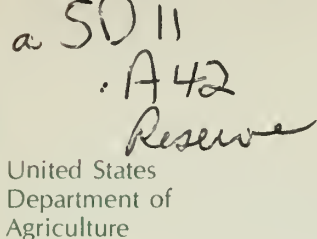


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**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

General Technical Report RM-151



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Meeting the Challenge of the Nineties:

Proceedings, Intermountain Forest Nursery Association

August 10-14, 1987
Oklahoma City, Oklahoma



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Abstract

This proceedings is a compilation of 27 articles on various phases of forest nursery management. Specific topics include: seed treatments, soil management, cultural practices, seedling quality, and nursery pests. Results of a discussion on the nursery competition issue are also presented.

NOTE

As part of the planning for this symposium, we decided to process and deliver these proceedings to the potential users as quickly as possible. To do this, we asked each author to assume full responsibility for submitting reviewed manuscripts in photoready format within tight deadlines. Thus the manuscripts did not receive conventional Forest Service editorial processing, and consequently, you may find some typographical errors and slight differences in format. We feel quick publication of the proceedings is an essential part of the symposium concept and far outweighs these relatively minor distractions. The views expressed in each paper are those of the author and not necessarily those of the sponsoring organizations. Trade names are used for the information and convenience of the reader, and do not imply endorsement or preferential treatment by the sponsoring organizations.

Meeting the Challenge of the Nineties: Proceedings, Intermountain Forest Nursery Association

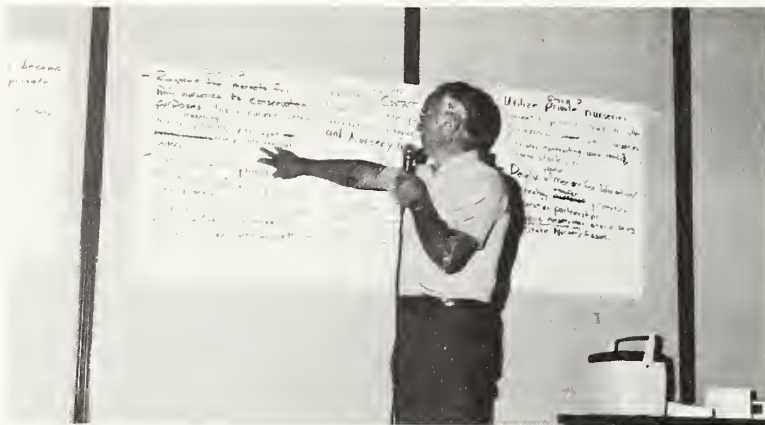
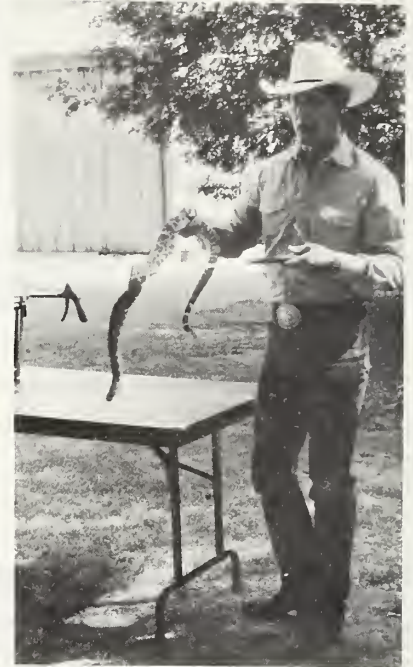
**August 10-14, 1987
Oklahoma City, Oklahoma**

Technical Coordinator:

**Thomas D. Landis
Western Nursery Specialist
Pacific Northwest Region
USDA Forest Service**

**Rocky Mountain Forest and Range
Experiment Station
Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado**

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Contents

Seedlings, Service, and Insights	1
<i>Carl E. Whitcomb</i>	
Communications as a Design Consideration in Developing a Computerized Nursery Management Environment	3
<i>John R. South</i>	
Applications of Portable Data Recorders in Nursery Management and Research	9
<i>W. J. Rietveld and Russell A. Ryker</i>	
Superabsorbent Hydrogels and Their Benefits in Forestry Applications	14
<i>Fernando Erazo</i>	
Organic Matter: Short-Term Benefits and Long-Term Opportunities	18
<i>John G. Mexal and James T. Fisher</i>	
The Trees Unlimited Program: An Experiment in Establishing Seedling Plantings	24
<i>Robert C. Oswald</i>	
The Potential of Soil Solarization in Nurseries to Control Soilborne Diseases	27
<i>Kenneth E. Conway</i>	
Seedling Production at Oklahoma Forestry Division Forest Regeneration Center	30
<i>Clark D. Fleege</i>	
Priming Treatments to Improve Pine Seed Vigor	33
<i>S. W. Hallgren</i>	
Effects of Nursery Density on Shortleaf Pine	36
<i>John C. Brissette and William C. Carlson</i>	
Polymeric Nursery Bed Stabilization to Reduce Seed Losses in Forest Nurseries	42
<i>William C. Carlson, John G. Anthony, and R. P. Plyler</i>	
Improving Outplanting Survival of Stored Southern Pine Seedlings by Addition of Benomyl to the Packing Medium	43
<i>James P. Barnett and John C. Brissette</i>	
Measuring Tree Seed Moisture Content Now and in the Future	46
<i>Robert P. Karrfalt</i>	
Forest Tree Nursery Herbicide Studies at the Oklahoma Forest Regeneration Center	49
<i>Lawrence P. Abrahamson</i>	
Use of Sulfur to Correct Soil pH	58
<i>Donald H. Bickelhaupt</i>	
Certified Vendor Program	66
<i>Thomas G. Boggus</i>	
Alternative Methods to Evaluate Root Growth Potential and Measure Root Growth	70
<i>W. J. Rietveld and Richard W. Tinus</i>	
Comparison of Time and Method of Mist Chamber Measurement of Root Growth Potential	77
<i>Karen E. Burr, Richard W. Tinus, Stephen J. Wallner, and Rudy M. King</i>	
Effects of Lift Date, Storage, and Family on Early Survival and Root Growth Potential of Shortleaf Pine	87
<i>S. W. Hallgren and C. G. Tauer</i>	
Fall Lifting: Its Effects on Dormancy Intensity of Ponderosa Pine Seedlings — A Preliminary Investigation	93
<i>Steven K. Omi and Ursula K. Schuch</i>	
A Status Report on Nursery and Reforestation Projects at the Missoula Technology and Development Center	98
<i>Ben J. Lowman</i>	

Grading Pine Seedlings with Machine Vision	100
<i>Glenn A. Kranzler and Michael P. Rigney</i>	
Mycorrhizae Nursery Management for Improved Seedling Quality and Field Performance	105
<i>Charles E. Cordell, Jeffrey H. Owen, and Donald H. Marx</i>	
Integrated Pest Management in Forest Nurseries	116
<i>T. H. Filer, Jr. and C. E. Cordell</i>	
The USFS Reforestation Improvement Program	120
<i>W. J. Rietveld, Peyton W. Owston, and Richard G. Miller</i>	
Government vs Private Nurseries: The Competition Issue	126
<i>Thomas D. Landis</i>	
Working Group Sessions on Communications and the Government/Private Nursery Issue	130
Session I: Communications	
Session II: Government vs Private Nurseries	
<i>Kurtis L. Atkinson</i>	
Minutes of the Annual Business Meeting	134
List of Attendees	135

Seedlings, Service, and Insights¹

Carl E. Whitcomb²

INTRODUCTION

Bed-grown tree seedlings have been produced for many years with variable performance at out-planting. Slowly, container-grown seedlings have gained in popularity in spite of their higher cost. But what about the future? Here is one practical research/practitioner's outlook.

Over the years much of the variability among seedlings has been attributed to genetics. If 100 viable seeds of most species are planted in a seed bed, the resulting seedlings generally grow at different rates. Container-grown seedlings are generally somewhat less variable. This slight improvement in uniformity is mostly attributed to more precise control of cultural conditions.

In the fall of 1985 the opportunity arose to examine the roots of 720 trees, 180 each of four species: lacebark elm, *Ulmus parvifolia*; shumard oak, *Quercus shumardi*; loblolly pine, *Pinus taeda*; and Chinese pistache, *Pistacia chinensis*. They had been grown in bottomless milk carton containers for approximately three months, then transplanted into two-gallon poly bag containers for the remainder of the first growing season and planted into the field in October. There were approximately 500 seedlings of each species in the poly bags from which the most uniform 180 were selected to minimize genetic variability. After two growing seasons in a sandy clay loam soil of moderate fertility, some trees had grown very little, while others exceeded nine feet in height and two-inch stem diameter. Could all of this variation be due to genetics or was something else involved?

Three days were required to excavate the 720 trees with a backhoe. All of the larger trees had large root systems but was this a factor of genetics? Counts of roots 3/4-inch in diameter or larger were poorly correlated with tree size. Counts of roots at a point approximately 12 inches from the stem were also poorly correlated with tree size. However, when counts of roots approximately 1/8-inch in diameter or larger arising

from the root/stem interface were taken, a striking correlation resulted (Figure 1). Only data and photo of the lacebark elm are included, since all four species responded similarly.

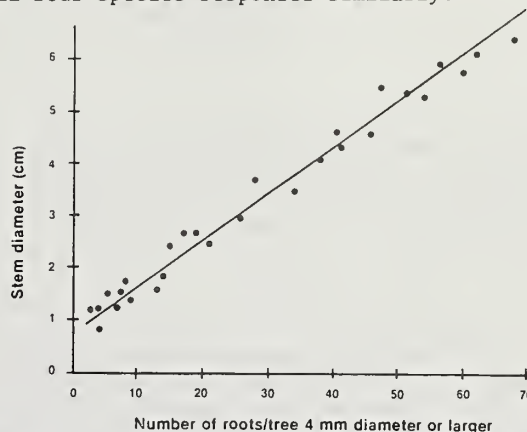


Figure 1. Relationship of number of roots arising from the root/stem interface and stem diameter of lacebark elm.

These data suggest that where the roots branch is very important and that this may be a major factor affecting the rate of tree growth. Thus, a genetically superior tree with a poor root system may only grow at a slow to moderate rate.

A NEW CONTAINER

To utilize this information, a unique new propagation container was designed. Called the Root Maker (U.S. and other patents pending), this container is 2.6 inches square and four inches deep and air-prunes the root system both at the bottom and on the sides (Figure 2). The bottom is shaped somewhat like a pyramid so that the tap-root and any secondary roots that reach the bottom will be air-pruned at one of four drain holes. Secondary roots that grow outward are guided to air-pruning openings in the sides. The four-inch depth forces secondary root branching at, or near, the base of the stem. Individual containers lock into a frame for ease of filling and handling and to insure proper spacing, yet can be easily removed for shipping or planting.

This data also suggests that bed-grown seedlings should be root-pruned early and perhaps often. A wider spacing will also be necessary to accommodate more lateral roots.

¹Paper presented at the 1987 meeting of the Intermountain/Great Plains Nursery Association.

²Carl Whitcomb is Research Horticulturist with Lacebark Research, Rt. 5, Box 174, Stillwater, Oklahoma 74074

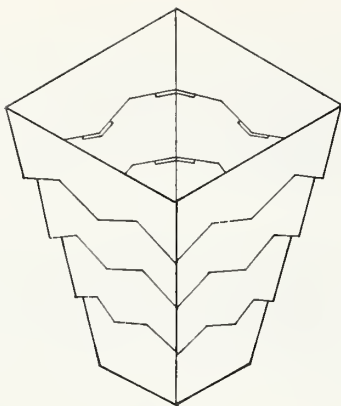


Figure 2. The Root Maker container air root-prunes tree seedlings on the sides as well as at the bottom. In addition, by controlling the depth, the root system is forced to branch at the root/stem interface to enhance tree growth.

NUTRITION

Proper nutrition can enhance plant growth and health and minimize other problems. The key is the synchronization of all of the essential elements. Studies with container-grown seedlings suggest that nitrate nitrogen, phosphorus, and the micronutrients are key factors.

Seedlings appear to have a limited capacity to utilize ammoniacal nitrogen, but do respond to nitrate. Phosphorus is very important. Potassium can vary considerably without affecting growth. The micronutrients play a key role in enhancing overall plant health and stem and root development. They can be added to the mix using research-formulated blends such as Micromax micronutrients that also provide sulfur.

The two major nutritional variables that are unique to each specific production site are calcium and magnesium. If pine bark or other wood product is used as a component of the growth medium, it should be analyzed for calcium and magnesium. However, the analysis must be done using an ammonium acetate extract to determine the levels available to the plant. Water extracts show only what will readily leach out. Strong acid extracts give inflated values due to partial or complete destruction of the particles.

Water quality is a variable that must be

considered in the production of both container and field production of seedlings. The levels of calcium and magnesium in the irrigation water play a key role in plant nutrition. In some cases, the irrigation water provides all of the calcium and magnesium needed. Other water provides only calcium, thus requiring a separate magnesium source. In the future, a water analysis plus growth medium analysis will be used to determine the levels of calcium and magnesium needed for optimum plant growth.

A related point is that the pH of the water gives little information regarding water quality. The pH gives only a measure of the acidity or alkalinity of the water, nothing more. A water may have a pH of 6 and contain considerable calcium or a pH of 9 and contain very little. A complete water analysis is the only way to know. Water with a high pH generally contains considerable bicarbonate which, if above about 200 ppm, must be considered in the nutritional program.

Bed-produced seedlings are affected by irrigation water quality as well. Due to the strong buffer of most soils, a longer time is generally required before the effects are noticed. Most soils labs suggest that a soil pH of 6 to 7 is ideal. This may be true for fast-growing annual crops such as corn, wheat, and soybeans, but it is not correct for trees. More precise management of this area as it affects nutrition will be required in the future.

Improved root systems in combinations with improvements in the entire water quality/nutrition complex and established good cultural practices will dramatically improve tree health, transplant success and subsequent growth. More precise production techniques will require more accurate monitoring by nursery managers. However, the payoff will be a superior product that requires fewer pesticides and is more uniform. The increased uniformity will allow further mechanization and labor savings. It all starts with the root system but the roots must be supplied with a precise nutritional program to maximize growth.

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Communications as a Design Consideration in Developing a Computerized Nursery Management Environment¹

John R. South²

Abstract: The transition from a manual to a computerized is successful only if the designers consider three levels of communications in the social and technical environments. In order of importance, these levels include communications among the staff members, communications between the staff and the computer, and communications between computers.

INTRODUCTION

The purpose of this paper is to examine how three levels of communications have played an important part in the development of the nursery management tool for Oklahoma. The three levels are:

- communications between members of staff,
- communications between the staff and the computer,
- communications between the various computers in the operation.

Consideration of the levels of communication has developed from the observation that the office environment is often viewed by management as being split between social and technical considerations. The author contends that, if the manager of a nursery wants to successfully convert from a manual to an automated operation, all three levels of communication must be considered.

COMMUNICATIONS BETWEEN STAFF MEMBERS

The 'traditional' manner of software development has been for the software designers to meet with the managers and supervisors of a particular operation and decide among themselves what software is needed to automate an office. The staff workers are not brought into the

picture until after the development process has been completed. Their first view of the system is when hardware and software are installed in the office. The group at the Forest Regeneration Center in Norman, Oklahoma have taken a quite different approach to the development of their system. From the first moment of development to the present time, the staff has been deeply involved in the definition of system specifications, design of the work flow in the system, and preliminary testing.

The most important role that the staff has played has been that of an information filter. The first meeting with the Oklahoma staff revealed the vast amount of paper work that an integrated nursery system would replace. In an ideal system, one of the goals of the development team is to filter the large amount of information for superfluous and redundant data (fig. 1). The members of the Oklahoma nursery have played that role of information filter.

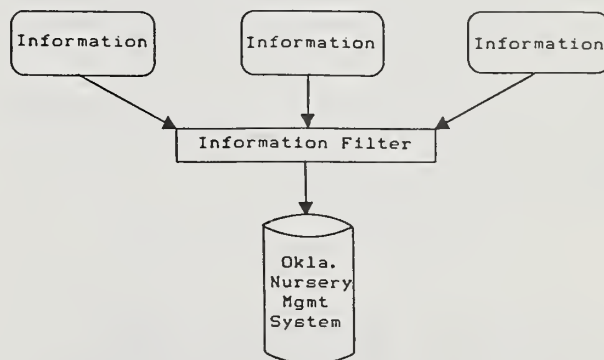


Figure 1 -- The Nursery staff acts as the filter which determines what information will be included in the automated system.

¹ Paper presented at the 1987 Intermountain Forest Nursery Management Association Meeting. Oklahoma City, August 10-13, 1987.

² John South is the President of Personal Computer Information Systems, Inc., Dallas, Tex. and Indianapolis, Ind. PCIS is a firm which specializes in software design, hardware sales and installation, and office automation.

collecting in the past. This whole process of bringing the staff into the design process has had ramifications which should last long after the automation process is complete.

Promotes a Spirit of Ownership

Bringing the staff into the development process promotes a spirit of ownership in the final product. This is important during the conversion process.

In a typical conversion process, the manual system runs parallel with the automated system. This means that the nursery staff will have to maintain both systems together for some specified length of time. The period is trying at best, but the path is much smoother when the staff feels that they have had a significant impact on the development of the product.

Provides a Creative Outlet

In the same light, including the staff in the development process allows these individuals to exercise their creative talents. It must be remembered that these are the individuals who have been performing the day-to-day tasks. Many have 'ideas' as to how the data should be collected, displayed, and reported. Involvement in system development provides a job enrichment unlike any normally available to the staff.

Lowers Resistance to Change

For long-term employees it may be difficult to accept a new way of collecting and reporting data, if an automated system is simply installed without their input. In some cases, change is a process that some staff members cannot accept; however, involvement in this type of a project at least gives the manager or supervisor an opportunity to whittle away at the resistance. Input from these long-term employees is important to the project. There may be a reason why the manual process should not be automated and this reason needs to be heard.

Reduces Training Time

A great deal of resources in the form of time and personnel may be needed to train individuals in the operation of the automated system. If these same individuals are part of the design process, they receive their training in an evolutionary manner as the project progresses. When they finish testing the final process, management will find that very little additional training will be necessary.

It is often seen that employees don't fear the changing process as much they fear the new technology. They are literally uncomfortable

when they sit in front of a computer for the first time. Given incremental doses of involvement with the computer helps to lessen the apprehension these individuals feel.

COMMUNICATION BETWEEN STAFF AND COMPUTER

The Integrated Environment

The Oklahoma Nursery Management System has been designed as an integrated environment. Though it does not encompass every function encountered in the management of a nursery operation, its operation does include most of the major data-generating activities (fig. 2).

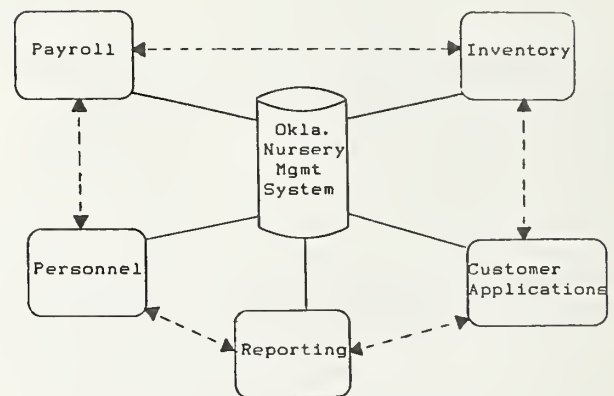


Figure 2 -- The automated environment showing the communication between the various submodules and the main environment.

As Figure 2 implies, the integrated environment was designed not only to bring all of the data activities under 'one program', but more importantly this type of configuration allows each submodule to 'talk' to those submodules which store data needed to complete a calculation. This environment is not one program but rather a number of programs linked together through a number of programming techniques. To the user, the nursery staff member, the movement from one submodule to the next is virtually transparent.

Figure 3 illustrates the concept of one submodule talking to another. In this case, the Payroll module (which, as one of its functions, collects information on cultural practices by hours for each particular species) needs the names of the species which the nursery is currently growing. So it 'asks' the Inventory module which species are currently being grown. On the other hand the Inventory module needs to calculate the cost of growing a particular species of seedling, so it 'asks' the Payroll module how many hours and in what cultural

practices time was spent on a particular species. Again, this transfer of information is totally transparent to the user, but is maintained by separate programs in the system.

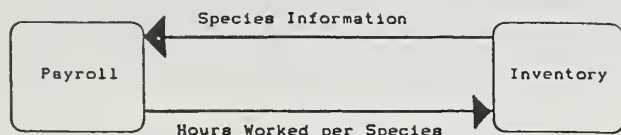


Figure 3 -- Transfer of information between two modules in the integrated environment.

A Dynamic Dialogue

Communications between the human staff member and the computer is a dynamic process. Interaction between the two entities changes from one day to the next. The problem that faces the system designer is that, once the program is installed, the program is, in a sense, in a static state. The process of moving from one part of the program to another does not change simply because it's Monday instead of Thursday. But the data and the database are dynamic. They are in a constant state of change.

Menus are the standard means of moving from one point in a program to the next (fig. 4). From the designers standpoint, menus are simple to program and they present no particular difficulty in error-checking. From the user's standpoint, menus are simple to use, self-documenting (to a point), and, in most cases, quite boring after the first few times though a program.

It seems to be a step backwards to involve your staff in the development of a computer system (where you are trying to unleash their creative talents), and then to saddle them with a system driven by one of the least creative selection mechanisms. The Oklahoma system only uses menus to move from one major program segment to the next.

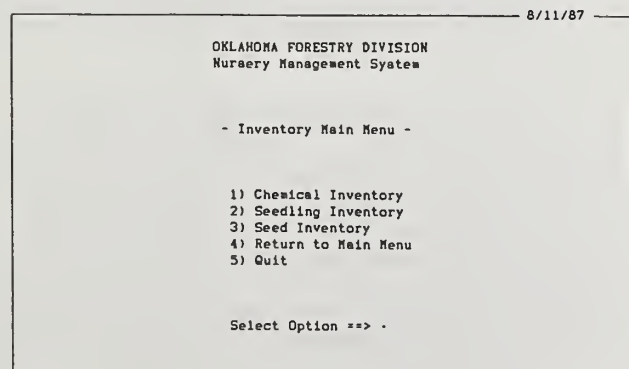


Figure 4 -- Menus are used only for movement from one major program module to another.

Data selection and data manipulation use one of two mechanisms. In a database environment, data records are selected by keys embedded in the data. In some cases a key may be an employee's name or social security number. In another case, a key may be a particular species or species code. In many cases, the key is a logical representation of the character string which actually retrieves the data. So the program must prompt the human for the information it needs to build the physical key. Figures 5 and 6 show two methods that the Oklahoma system uses to prompt the staff member for the necessary information to build a key.

In the first case (fig. 5), the staff member is using the Payroll submodule and is about to add hours (specified by cultural practice) to an employee's record. The individual entering the data is using the employee's social security number to pull up the employee's work history. The social security number may have been the only means the staff member had of identifying the employee, or the staff member may have felt that using the social security number was a faster means of getting to a particular employee's record. The point should be made that using either the name or the social security number of the employee would have led to the same record. In this case, name and social security number are alternative keys for a particular employee's record.

```

8/11/87
OKLAHOMA FORESTRY DIVISION
Add Hours By Category

- Enter Name Or SSN -

1) Last Name :
2) First Name:

3) SSN: 111-11-1111

- Enter The Beginning Date For Period Worked -

4) Begin Date: 08/11/87

PRESS *ESC* TO GO TO MAIN MENU
  
```

Figure 5 -- Data selection through alternative keys. The computer prompts the user for the information needed to locate an employee's record.

Though figure 5 appears somewhat like the menus that were slandered above for their inherent lack of creativity, the difference between the two is that in using a key screen, like that in figure 5, the staff member needs to make decisions. The first decision is what key to use. If an employee is not located using that key, the user needs to decide what alternative key to use to perform the search.

Figure 6 illustrates another mechanism which the Oklahoma system uses for gathering

information it needs for generating a key. The user is in the Inventory module and wants to add Ponderosa Pine to the species inventory. Rather than flipping to a separate screen to ask for the species name or species code, a window automatically pops up on the screen indicating to the user that the computer needs some information before it can continue its processing. The message in the bottom of the pop-up window indicates that the user used the species name as a key to the species' records. Since no species record existed for Ponderosa Pine, the computer indicates this fact and asks the user for the species code in order to complete the initial construction of the species record.

8/11/87

OKLAHOMA FORESTRY DIVISION
 Species Addition Option

Enter Active Species

1) Species Name: Ponderosa Pine

2) Species Code: 11.....

New species - please enter Species Code

PRESS "ESC" TO GO TO MAIN MENU

Figure 6 -- A pop-up window which prompts the user for information needed to construct the key for new species record.

The final method the Oklahoma Nursery Management system uses for obtaining a key to a specific record is shown in figure 7. Again, the pop-up window mechanism is used. In addition to alerting the user to the fact that the computer needs some piece of information, the pop-up windows eliminate a number of screens and, in some cases, a number of menus.

8/11/87

OKLAHOMA FORESTRY DIVISION
 Species Update Option

Select Active Species

Species Name	Species Code
1 Arborvitae	01
2 Austrian Pine	10
3 Autumn Olive	25
4 Bald Cypress	15
5 Black Locust	02
6 Black Walnut	08
7 Catalpa	03
8 Euonymus	27
9 Green Ash	14
10 Hackberry	18

PRESS "ESC" TO GO TO MAIN MENU

Figure 7 -- A pop-up window which allows the user to select a given species from the list of active species.

The difference in the case of figure 7 is that the choices presented to the user are fed to the pop-up window straight from the species database. The user selects the species to update by moving a cursor to the left of the number corresponding to the species of interest. By pressing the enter key, the selected species is brought into active memory and is available to the user for update.

Data Entry - A Model of Simplicity

Next to manipulating the data (producing statistics and reports), the most important function of any data processing system is incorporating data into the database, i.e. data entry. Many designers disagree on the level of sophistication of a data entry screen; but, there is no disagreement on the fact that data validation is a primary concern of the system designer. The integrity of the database is protected only to the extent that the designers provide for error checking when designing the screens. There are two basic data entry screens being used by the Oklahoma Nursery Management System. A conventional screen (fig. 8) is used for gathering most of the raw data for the database records.

8/11/87

OKLAHOMA FORESTRY DIVISION
 Personnel Update Option

1) Last Name : South

2) First Name: John R.

3) Address: 6909 Custer Road, #708

4) City : Plano

5) State: TX 6) Zip: 75023

7) Phone Number: (214)964-2670

8) Soc. Sec. Nbr: 111-11-1111

9) Position: Area Forester

10) Employee Type: PERM

11) Area: C&W

12) Job Code: U102

13) Grade Step: 062-7

14) Hourly Rate: 9 15.97

15) Start Date: 08/11/87

Next Action?

PgUp-Next Rec PgDn-Prev Rec F2-Change F3-Cont ESC-Quit

Figure 8 -- A data entry used to enter personnel information. Each field is validated for type of data, length of the data field, and the range of the data.

Not all the information shown in figure 8 typed in by the user. The Oklahoma system is designed to put information on the screen for the user once it has enough data to perform this operation. For instance, in figure 8 the user would type in the employee type (PERM), area (C&W), and the job code (U102). The system determines that this data corresponds to an Area Forester of Grade 62. The user then entered the step (7) and the computer responded with the hourly rate (\$15.97).

Figure 8 also illustrates one of the primary design features of the Oklahoma Nursery

Management System. At the bottom of the window is a key selection menu. If the user were to press the PgUp key, the system would bring the next personnel record up on the screen. Pressing PgDn would bring up the previous record. This one key operation is designed throughout the system and allows the user to move through the database and to select particular operations without having to go another menu or another screen.

In some cases, a large amount of numeric data needs to be entered into the database. The Oklahoma system handles this by providing a matrix-like screen system (fig. 9). The upper part of the screen indicates the data record the user is working with; the bottom part of the screen is used for the data entry. Since not every field will be used for storing data, the user can move the cursor to the proper fields (not unlike a popular spreadsheet package).

OKLAHOMA FORESTRY DIVISION			8/11/87
Add Hours By Category			
Name:	South, John R.	SSN:	111-11-1111
Address:	6909 Custer Road, #708	Job Code:	U102
	Plano, TX 75023	Area:	C&W
Position:	Area Forester	Type:	PERM
Enter Time Spent On The Following Categories For: 08/11/87			
1) Chemicals >	10) Seed Inven.>	19) Count/Tie >	
2) Hand Chea. >	11) Equipment >	20) Topcut >	
3) Weeding >	12) Grounds >	21) Seed Harv. >	
4) Fertilizer >	13) Seed. Rec. >	22) Seed Proc. >	
5) Soil Amend.>	14) Training >	23) Planting >	
6) Irrigation >	15) Adwin. >	24) Cult. Pact.>	
7) Site Prep. >	16) Shipping >	25) Misc. 1 >	
8) Cover Crop >	17) Ship. Admn. >	26) Misc. 2 >	
9) Research >	18) Mech. Harv.>	27) Misc. 3 >	
Day's Comments: F2-Enter Comments F3-End Total Hours:			
PRESS 'ESC' TO GO TO MAIN MENU			

Figure 9 -- Numeric data is entered into the database through a matrix-like screen.

In the case of figure 9, the user is entering the hours that a particular employee has spent working on the listed cultural practices. Since the hours spent on some cultural practices (for instance, weeding) need to be broken down to the species which were worked, the Oklahoma Nursery Management System alerts the user to this fact by generating a pop-up window which allows the user to enter the appropriate data (fig. 10).

COMMUNICATIONS BETWEEN COMPUTERS

Communications between computers is an area which is beginning to receive a great deal of coverage in the computer press. This media coverage is doing more for the sales of expensive communications hardware and software than it is for generating legitimate development ideas in operations converting from manual to automated processes. There is no doubt that many operations will eventually evolve into systems which can effectively take advantage of concepts such as local area networking, distributed

OKLAHOMA FORESTRY DIVISION		8/11/87
Add Hours By Category		
Name:	South, John R.	SSN:
Address:	6909 Custer Road, #708	Job Code:
		U102
		C&W
		PERM
Please Breakdown 2.00 Hours Over Species Worked On		
Arborvitae >	Aust. Pine >	08/11/87
Cypress >	Aust. Pine C>	nt/Tie >
Black Locust>	Pond. Pine >	cut >
Black Walnut>	Scotch Pine >	d Harv. >
Euonymus >	Shtleaf Pine>	d Proc. >
Green Ash >	Virg. Pine >	nting >
Hackberry >	Imp. Lob. Pine>	t. Pact.>
Lacebark Elm>	Cottonwood >	c. 1 >
Mulberry >	Baldcypress >	c. 2 >
Osage Orange>	Bur Oak >	c. 3 >
Pecan > 1.00	Catalpa >	
Red Cedar >	M. Rose >	
Russ. Olive >	Redbud >	
Autumn Olive>	Sand Plus >	
Total Hours:		Total Hours:
2.00		6.00

Figure 10 -- A pop-up window which prompts the user for the hours by species for a particular cultural practice.

processing, and mainframe links. From what the author has seen over the past few years, some system designers get caught up in the technology and overlook the true purpose of the system. In fact, in some cases, they go so far as to purchase the hardware and then try to make the system fit the hardware.

WRONG!

The conceptual design of data acquisition and database manipulation needs to be considered first. Granted, the specifics of a particular system may necessitate a hardware intensive design, but that decision should not be made until the database design is well thought out.

In the case of Oklahoma, the nursery system is designed to be a stand-alone system. But it is also designed in such a way that, should the Forestry Division decide to expand into a different configuration, the software can be modified relatively easily to meet the changing environment.

The current system is designed to use rudimentary data communications techniques as illustrated in figure 11. The communication techniques are rudimentary in that the data files are transmitted from one node to the next manually. For instance, the Area Forester can transmit a set of data files to his Supervisor in the capital. In another case, the author's firm can transmit the latest version of a particular report schema to both the capital's computer and to the computer at the Forest Regeneration Center. The point to be made is that this is all the high tech communications the operation needs at this point in time. Some day the nursery in Norman may operate as a node in a distributed processing environment with the capital, but that day is still a ways off. The managers in that operation have made the decision to concentrate on their software environment and to develop the overall system (hardware) as an incremental process.

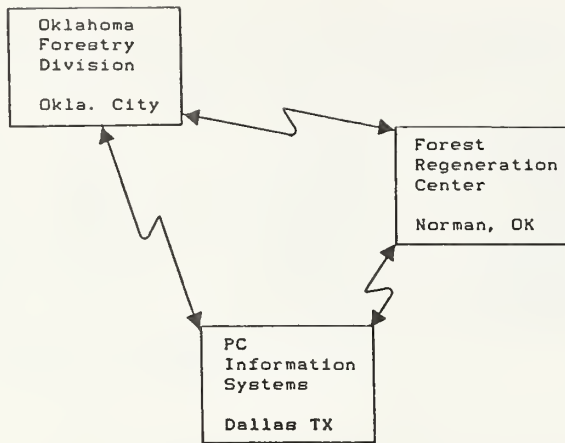


Figure 11 -- Communications between the computers involved in the Oklahoma Nursery Management System.

FINAL COMMENTS

Of the three levels of communications which

the system designers need to consider when converting a manual operation to a computerized environment, the most important area of communications (from the standpoint of the nursery) is the communication among the members of the staff. This level of communications has the most far-reaching impact and will have the greatest long-range effect on the individuals in the operation.

It is inherent that the system designers stress simplicity when they develop a particular automated environment. This will lead to less resources being devoted to training and will alleviate the frustrations that the non-professional computer user feels when working with a system that is not self-documenting.

Finally, it is important that the system designers understand how hardware, software, and the evolutionary stage of the development process all relate to each other. Though it would be nice to incorporate all the neat, sophisticated hardware available, in most cases, during the manual-to-computer conversion, these high tech gadgets are inappropriate.

Applications of Portable Data Recorders in Nursery Management and Research¹

W. J. Rietveld and Russell A. Ryker²

Abstract.--A portable data recorder is a specialized electronic device for recording and storing data in the field, then transmitting the data directly to a computer, eliminating the time and errors associated with manual data transcription. Use of a data recorder allows error and completeness checking in the field, direct data collection from instruments, and minimum turnaround time between data collection and completed data analysis. Considerations for selecting a data recorder to meet individual needs, and some drawbacks, are discussed. Specific applications in nursery management and research are presented.

INTRODUCTION

A portable data recorder (PDR) is a hand-held, battery-powered, microprocessor-controlled computer terminal (Cooney 1987). PDR's are specialized electronic devices designed to collect and store data in the field or laboratory (in place of data forms), then transmit the data directly to a computer for processing. They differ from laptop computers and hand-held calculators in that they are constructed for outdoor use and their main purpose is to store data, not process it. As microcomputer use increases in forestry, more resource professionals are turning to automated data processing to increase their productivity. Although computer hardware and software have advanced substantially in recent years, data are still collected and entered into computers by hand in many cases. These two steps done manually can be expensive, time-consuming, and full of errors. Alternatively, data can be keyed into a PDR as they are collected, automatically checked for errors and completeness, then the completed data file can be transmitted directly to a computer. Because manual data transcription is eliminated, PDR's can significantly reduce costs, number of errors, and turnaround

time. PDR's are becoming the technological link between field measurements and data analysis.

Portable data recorders were first used in supermarkets to expedite inventories. In recent years they have found a new home in forest inventory because of the volume and diversity of data that are collected, the need for error checking during data collection, cost savings in data transcription, and reduced time to obtain results (Anonymous 1987, Bergstrom 1987, Bottenfield and Meldahl 1987, Fins and Rust 1987, Scott 1987). Bluhm (1986) recently reported using a PDR in nursery seedling inventory. Applications in research have increased in recent years, not only because more efficient data handling is needed, but also because some PDR's can be interfaced to digital and analog instruments to collect data directly.

All these applications have certain characteristics in common: (1) a large amount of data needs to be collected and transferred to a computer for summary, (2) the costs of manual data entry and verification need to be reduced, (3) errors must be minimized, and (4) the time between data collection and data processing should be reduced. In this paper, we will discuss some benefits and drawbacks of using PDR's, list some considerations to help you decide which one to purchase, and present some ways we use PDR's in nursery management and research.

¹Paper presented at the Intermountain Forest Nursery Association Meeting, Oklahoma City, Oklahoma, August 10-14, 1987.

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SELECTING A PORTABLE DATA RECORDER

Approximately two dozen devices on the market could qualify as portable data collectors. Specifications for most of the dedicated PDR's are reviewed by Cooney (1985, 1987). They differ

widely in size, environmental durability, keyboard configuration, operating system, memory capacity, programmability, and communications. Most are powered by rechargeable batteries, have some form of battery backup, and have some sort of low battery warning, so there is a low risk of losing data. The devices differ greatly in other specifications; users need to determine what configuration they need and select the appropriate device. For example, in forest inventory error-checking and completeness checking routines should be built into the data collection scheme so that complete and error-free data are obtained while the survey crew is on site. For those applications, a PDR that supports BASIC, a powerful and versatile programming language, is highly recommended. Many other applications are more straightforward, amounting to filling in the blanks with data, so a simple edit mode may suffice for entering data. Certain PDR's can be interfaced with digital and analog instruments -- such as calipers, balance, area meter, porometer, thermometer, and string potentiometer -- so that data can be transmitted directly to the data file with the push of a button. In some cases the PDR can be set up to take unattended readings from an instrument at set times. Note, however, that these applications require a custom program to read the device and record the data. All PDR's are equipped with a serial port for RS-232 communications via direct cabling or a modem to a host computer.

Programmability is desirable for controlling cursor movements, performing mathematical functions, displaying menus and messages, checking for errors, checking for completeness, and accepting data from interfaced instruments. Most devices provide some degree of programmability using either a proprietary language that the user must learn, or BASIC, a more universal language. Although the proprietary languages can be used to provide extensive error checking and to perform mathematical functions, there are advantages to purchasing a PDR that is programmable in BASIC because the same language can be used for programming on a microcomputer. However, a proprietary language may be more suitable for programming the PDR to accept data from connected instruments. While building in some programmed error checking routines and minor manipulations of the data may increase efficiency of data collection, don't expect the PDR to perform the data summary and analysis. For most applications, it is easier to first transmit the data to a computer, then perform the analyses using existing, more powerful application software. The examples in the applications section will illustrate this point.

We recommend the following approach to selecting a PDR: (1) list all applications where a PDR may be useful, (2) evaluate that list and retain only the applications where a PDR is truly needed to increase efficiency (i.e. large amounts of data, repetitive measurements, need to transmit data to a computer, minimization of errors, and cost savings from eliminating data transcription), (3) make a list of capabilities

and features that the PDR must have to meet your needs, (4) compare your list against the tables of specifications provided by Cooney (1985, 1987), and (5) evaluate product information and any available published reports in making your decision. Several companies and agencies have conducted their own evaluations and may be willing to share their information.

You may also wish to evaluate the economics of using a PDR instead of conventional field forms and manual data entry. You can do this by following the procedure outlined by Fins and Rust (1987). Assuming that data collection takes the same amount of time by both methods, data transmission and manual entry times can be estimated closely enough to perform the comparative cost estimates without actually using a PDR.

DRAWBACKS TO USING A PORTABLE DATA COLLECTOR

Some special problems, limitations, and conflicts that may be encountered in using a PDR are: (1) "computer phobia", (2) limited view of the data file, (3) conflict with existing data collection methods, and (4) cabling and communications between connected devices.

Many people get "computer phobia" when they are asked to record numbers electronically rather than writing and storing them physically on a tangible sheet of paper. The task of training personnel to use a PDR should be taken seriously. It is a good idea to develop flow charts and provide practice data for them to learn with before important data are recorded. As a transition, it may be helpful to first write the data on data forms, then enter the data into the PDR.

One limitation of most PDR's is the restricted view of the data file, i.e. only a small portion of the file is seen (and accessible) on the display at one time. It is more difficult for the user to compare current measurements with previous measurements, which are more easily seen on data forms. This is not a problem if you take advantage of the PDR's power by writing a short program to have the PDR display the previous measurement (which must exist in the same file), or you can have it compare the new measurement with the previous measurement, beep if it is smaller, and otherwise enter the data in the file. A second problem related to the restricted view is keeping track of your location in the file. Because one row in the file is usually the data for one tree, beginning users may skip a tree and get out of sequence with the data file. There are two ways to avoid this problem. One is to print a copy of the data file with lines numbered so users can keep track of their location by line number, and the other is to program the PDR to display the descriptors (e.g. block, treatment, tree number) pertinent to each measurement being entered.

Use of a PDR may not be compatible with established plot measurement methods. For

example, some crews like to have one person record data while two people measure trees in adjacent rows. This does not work out very well using a PDR because it cannot easily switch back and forth in the data file. The same is true for measuring adjacent rows in opposite directions, unless either the plot or the data file is arranged that way. When using a PDR, it is easiest to enter data in the sequence they occur in the data file. If more than one person is taking measurements, they should leapfrog and provide the data in the file sequence.

Cabling and communications between connected devices are common obstacles when any peripheral device is connected to a computer or PDR. Cabling from a PDR to a microcomputer is usually not a problem because the manufacturer often has a serial cable available. Communications between a PDR and a computer is best done with a communications program. Establishing communication is a matter of setting up matching protocol (baud rate, parity, duplex, data bits, stop bits, etc.) between the two devices. The PDR manual will usually give some helpful advice on this, but there is no one solution because computers differ widely. The same situation arises when a PDR is cabled to an instrument to collect data. In some cases, e.g. digital calipers, the device, cable, and programming may be available from the PDR manufacturer. In other cases, you purchase the peripheral device with its optional serial port, and the cabling and communications to the PDR are up to you.

SPECIFIC APPLICATIONS OF PORTABLE DATA RECORDERS

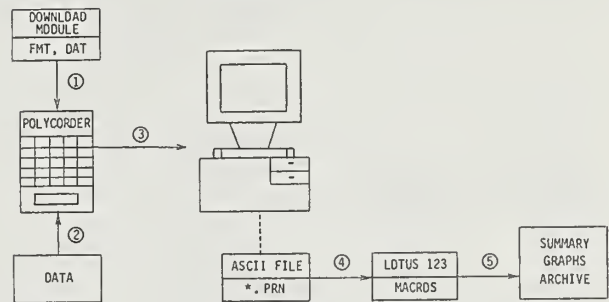
In this section we will present two applications of the Polycorder³ (Omnidata International, Logan, UT) in nursery management and research. Published applications of other PDR's are: Hewlett-Packard model 71 (Bluhm 1986); Husky Hunter (Bergstrom 1987, Bottenfield and Meldahl 1987); Husky Special Performance (Scott 1987); Oregon Digital Serial Plus II 7100 (Anonymous 1987); and Datamyte 1003 (Nieman et al. 1984).

Nursery Application

The USDA Forest Service Reforestation Improvement Program (Rietveld et al. 1987) involves repetitive measurement of several seedling variables (seedling growth, morphology, root growth potential, cold hardiness, stress test, plant moisture stress, and field plot measurements) at 11 nurseries. The same variables are repeatedly measured using the same sampling scheme, so the basic data forms will be used over and over. To facilitate data collection, summarization, file organization, and archiving, a systematic

³The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

approach was developed that utilizes the Polycorder to record the data and transmit it to a microcomputer. The following diagram shows how the data will be processed:



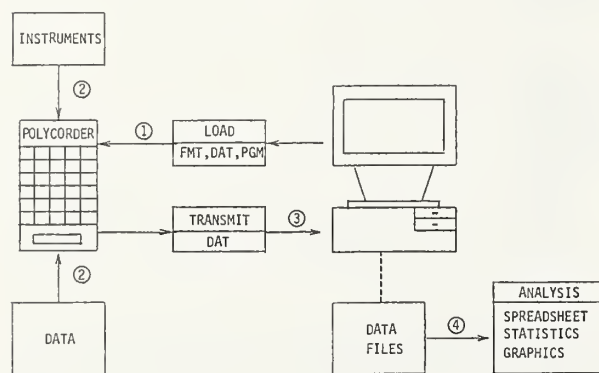
The Polycorder requires a format file for each data file that will be created. The format file designs the data form. The data file is the actual form, which is blank until data are entered. Format and data files may be keyed into the Polycorder, loaded from a download module (1), or downloaded from a computer. The next step is to key the data into the data file (2). This can be done in edit mode or in program mode, but the latter requires writing a short Polycode program to control cursor movements and must be matched to the number of columns receiving data. Once the data file is complete, the data are transmitted to the computer (3) using direct cabling between serial ports on each device. A communications program, Crosstalk, is used to capture the data and create an ASCII file with a .PRN extension. The ASCII data file is then imported into a preformatted Lotus 123 worksheet (4) where the data are summarized, graphs are created, and archiving is done (5) by running specialized macros (preassembled lists of commands) on the worksheet.

This scheme offers many conveniences as a result of the repetitive nature of the application: 1) because the same data files are used over and over, they may be stored in a download module (or the computer) and loaded into the Polycorder whenever they are needed; 2) after the data are offloaded to a computer, they may be erased from the Polycorder file, retaining the blank data file in the Polycorder for reuse; and 3) automated data processing is optimized, thus the data can be transmitted to a computer and summarized in minutes.

Research Application

The above approach works well for repeatedly measured variables where the same data forms are consistently used. However, that is often not the case in research. Each study typically has one or more unique data files; the data files will usually be more complex, e.g. containing several columns of descriptors for block, treatments (in random order), and seedling number;

there may be a need to append additional columns onto the original file for annual measurements; and some data types may be transmitted to the PDR via a serial port from a digital balance, calipers, area meter, porometer, or other device. The following diagram shows a typical data collection and processing scheme in research applications of PDR's:



The format and empty data files are more easily created on a computer, stored as ASCII files, then downloaded directly to the Polycorder (1). The format file can be written with EDLIN or any word processor that will output an ASCII file. The data file containing the descriptors (block, treatment, tree number, etc.) in the desired sequence can be "constructed" using Lotus 123, or can be created directly with certain statistical programs such as Minitab. The ASCII format and data files are downloaded to the Polycorder using a communications program. This step can be expedited by using a communications program that has versatile command and script file capabilities. An example is presented in Table 1.

Data are entered into the PDR through the keyboard (2) or by direct transmission from instruments (2). Direct transmission of data from instruments is very fast, but requires that a Polycorder program be written to accept, manipulate, and file the transmitted data. For example, we weigh dried plant samples without removing them from the bags. Paper bags of the same size are surprisingly consistent in weight. We dry a group of empty bags along with our plant samples, determine an average empty bag weight, then enter that value into a Polycorder program. The program subtracts the measured weight from an alphanumeric string transmitted by the balance, subtracts the average empty bag weight, records the tissue dry weight in the data file, performs cursor movements, and provides file location prompts. This technique works well for samples that have a dry weight greater than 1 gram; the experimental error is no greater than that introduced by removing the plant samples from the bags to weigh them.

The completed data file is transmitted back to the computer (3), using a communications program. File redirection programs such as Dpath and File Facility are handy for organization purposes because they allow you to store data files in separate subdirectories on a hard disk, rather than storing them all in the same subdirectory with the communications program. The final step of the scheme shows the data files being imported into various spreadsheet, statistical, or graphics programs for analysis (4).

DISCUSSION

Portable data recorders have the potential to increase efficiency of data collection in a variety of applications. However, they are not for everyone. Converting to a different method

Table 1. A Crosstalk script file (*.XTS) for transferring files between a PDR and a microcomputer. The script file loads automatically when it is given the same prefix as the command file (*.XTK). The communication protocols used in the command file must match those of the PDR.

```

GO LOCAL
CLEAR
ASK Type L for Load, T for Transmit, E for Edit, or Q for Quit
JUMP DO-@
LABEL DO-Q
QUIT
LABEL DO-L
SCREEN D
CLEAR
LWAIT CHAR " " ;insert mating call character sent by PDR, if used
SEND
RWIND
LABEL DO-T
SCREEN D
CLEAR
CA
WHEN " " ALARM NOW ;insert end of file character sent by PDR
WAIT STRING " " ;insert end of file character sent by PDR
CA -
RWIND
LABEL DO-E
RUN
  
```

requires an investment in new equipment, and time to evaluate the actual need for the device, to learn how to use it, to develop a system to apply it, and to train personnel to use it properly. Thus, there will be a start-up period before a net increase in efficiency is realized. You should be reasonably certain that using a PDR is justified before you make a commitment. Use of a PDR (and a computer for that matter) may well help you reach a higher level of technology, efficiency, and productivity. However, that is only achieved through learning, commitment, and adaptability.

In research applications, we find that using PDR's allows us to take more data than would otherwise be possible with available personpower. This is especially true when instruments are interfaced with a PDR. One person can take several times more data in a single day, with good precision and less fatigue. Most technicians are enthusiastic about using data collectors because they save time, and the person feels a sense of accomplishment for mastering the use of a sophisticated electronic tool. Because data entry and verification are eliminated, the technicians are relieved of those tasks, and the computer is freed for other uses.

In summary, PDR's are a cost-effective alternative to conventional data sheets for data collection and manual entry of data into a computer. Data collection time is about the same with a PDR, but the need for manually entering data into a computer and verifying them is eliminated. Other benefits are the opportunity to perform error checking in the field, interface with instruments, and obtain faster turnaround of completed data analyses. In general, if a PDR is used frequently, the labor savings will pay for the device in 1-2 years.

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Superabsorbent Hydrogels and Their Benefits in Forestry Applications¹

Fernando Erazo²

Abstract.--Superabsorbent hydrogels applications for forestry use have been developed over the last few years and are now being used as soil additives in growing containerized seedlings and as "ROOT-DIP" prior to packaging and storage.

INTRODUCTION

AGLUKON AGRI-PRODUCTS is part of the worldwide group of Schering Agrochemical Companies.

In Europe, it is estimated that 60% of pine trees are affected by acid rain. Schering (AGLUKON S.D.) is the founding researcher company that in 1984 started and successfully developed products to prevent damage of acid rain in young and established pines.

In the U.S., Schering (AGLUKON) has been marketing agricultural superabsorbents since 1979. In 1982, we built the first U.S. synthetic hydrogel facility for agricultural applications. AGLUKON is the manufacturer of ROOT-DIP superabsorbents.

In 1987, AGLUKON will introduce, for trials, a specialty foliar potassium compound for hardening of seedlings. This could allow nurserymen to lift seedlings even if weather remains warm.

1. WHAT ARE SUPERABSORBENTS?

Crosslinked polymers that absorb and retain fluids hundreds of times their own weight, are called superabsorbents.

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The ability to absorb and retain water and other fluids, has encouraged many a company to seek a variety of applications:

Health Care--Diapers, sanitary napkins

Industrial Use--Municipal water treatment, wipers, oil mudding

Agriculture--?

2. ADVENT OF SUPERABSORBENTS IN AGRICULTURE

It is difficult to believe that we are in the third decade of some form of superabsorbent usage. (See Table 1.)

3. TYPES OF SUPERABSORBENTS

The 1960's

In the early sixties, the Agricultural Research Group of Union Carbide already had developed a hydrogel that absorbed up to 40 times its own weight in water...this was a polyethylene polymer combined with sawdust... a soft gel designed to be mixed with soil, to improve water capacity and aeration of soil mixes. This was the first gel developed specifically for horticultural practices.

The USDA in Illinois then discovered that crosslinked acrylonitrile with corn starch could also absorb over 100 times its own weight in water. The USDA licensed several companies to produce such a superabsorbent gel. Most of these designed uses for health care, and some agricultural segments.

Several companies also produced cellulose gels, and research for synthetic hydrogels had begun.

TABLE 1.--TYPES OF SUPERABSORBENTS

Chemical Name or Ingredient	Market Application	Period
Polyethylene Oxide/sawdust	soil amendment	1965-1978
Polyvinyl Alcohol	diapers	1975-present
Acrylonitrile/starch	tampons, napkins	1979-present
	soil amendment	1966-1983
	planting seedlings	1978-present
Potassium Propenoate/Propenamide copolymer	soil amendment	1978-present
(Potassium Polyacrylamide/Poly Acrylate Copolymer)	gel seeding	
Acrylic Acid (polyacrylates)	plug-mix planting	1982-present
	root-dip	
	diapers	1981-present
	sanitary napkins	1982-present
	water treatment	1983-present
	soil amendment	1984-present
Acrylamide (polyacrylamide)	diapers	1983-present
	sanitary napkins	1984-present
	soil amendment	1983-present
Acrylic Acid/Acrylamide (combinations)	diapers	1985-present
	soil amendment	1985-present

the 1970's

The early products that combined a synthetic polymer with natural polymers penetrated on a small scale, several areas of horticulture and many trials were conducted in agricultural applications, including planting of bare-root seedlings.

In the late seventies, however, researchers in the U.S., Japan and England announced the discovery of different types of synthetic superabsorbents, which sought to eliminate the problems associated with natural polymers.

Most of these newly discovered superabsorbents found a home in the diaper industry, and only one in the U.S. built a facility and began application and product development solely for agricultural uses.

the 1980's

Several of the manufacturers of superabsorbents for diapers and municipal water treatments are now seeking to expand their market into all segments of agriculture.

Many of these products are not fit for our industry. Therefore, it is our responsibility to know why.

It is also our responsibility to recognize which of the superabsorbents are good for agricultural applications.

Proven technology has now been developed and is in place for specific segments of agriculture, horticulture, forestry. This technology application is based on the choice of a correct product for a specific application.

4. APPLICATIONS PRACTICED IN HORTICULTURE AND AGRICULTURE

Propenoate propenamide copolymers are successfully used as follows:

Soil Additive

- to increase water holding capacity
- to improve aeration and drainage of soil mix
- reduce irrigation frequency
- increase shelf life
- maintain moisture equilibrium

The superabsorbent must be able to release water when the moisture equilibrium of the soil changes, or as the roots need it.

Major uses are in container growing and tree and shrub planting.

Growing Of Transplant Plugs In The Greenhouse

The advantage is that the "chunks" of gel are carried from the greenhouse to the field in each plug, thus...

- not only has the grower received the benefit while growing the plug, but
- he can also eliminate transplant shock during transplanting operations

Fluid Drilling Or Gel Seeding Of Pregerminated Seeds

In this case, the superabsorbent gel must make a perfect suspension, soft, but consistent, to protect the delicate 2 mm seedlings while they are extruded to the soil.

Root Dipping Applications

It is now well proven that a major factor in field survival of bare-root seedlings is the proper treatment and handling of seedling roots prior to planting them. Root dipping with the correct gel will fulfill that need.

5. USE OF THE CORRECT SUPERABSORBENT IN FORESTRY APPLICATIONS

Soil additive for growing containerized seedlings.

Root dip spray for bare root seedlings, after lifting, prior to storage.

6. SOIL ADDITIVE FOR GROWING CONTAINERIZED SEEDLINGS

System

The small granules of superabsorbents are thoroughly blended into the peat mix prior to filling the plugs.

"Viterra" absorbs free water that is normally lost to leaching. As the "Viterra" granules expand, the soil volume increases and aeration and drainage improves. Each granule acts as a tiny water reservoir, replenishing moisture as the soil dries out, or absorbing excess moisture. Essentially, "Viterra" acts as a buffer in your soil, stabilizing the moisture levels for optimum root development.

Benefits

The small amount of superabsorbent will create optimum growing medium with consistent moisture equilibrium, resulting in a homogeneous size seedling which can reduce grading activity with less frequent irrigations.

An additional benefit is that the containerized seedlings already have hydrated gel "chunks" to protect against transplant shock, and give the forester a better stand.

Rates

Mix 1.5 lbs. of superabsorbent for each cubic yard of mix OR 1 oz. per cubic foot of mix.

7. ROOT DIP SUPERABSORBENT FOR BARE ROOT SEEDLINGS

A nursery can now choose the easiest, least messy, labor prompt and most effective method from the following:

- a. root packing with peat moss
- b. dipping in a clay slurry
- c. spraying with ROOT-DIP superabsorbent

If we are concerned with field survival of bare-root seedlings, we must give their roots the best care and treatment available. ROOT-DIP will keep the roots in a moist condition, and will prevent root "dry-out" during storage and shipping.

How to use ROOT-DIP

Easy to use. There is no need for special equipment to produce a ROOT-DIP slurry suspension. Just add the correct rate of ROOT-DIP to water. Wait a few minutes to hydrate, and your ROOT-DIP treatment is ready!

Spray the bare-root seedlings with ROOT-DIP slurry.

The tiny water-laden gel particles will cling to the seedling roots, and will replenish moisture to the roots during storage and shippings.

Rates

One pound of ROOT-DIP for 33 gallons of water is sufficient to treat up to 15,000 bare-root seedlings, at an average cost of \$.367/1,000 seedlings, or less.

8. BUT...

Let's remember that not all superabsorbents are the same. (See Table 2.)

In fact, ROOT-DIP superabsorbent is good for treatment of bare-root seedlings, but not good for treatment of baby diapers.

9. WHAT TO LOOK FOR IN A ROOT-DIP GEL

- Non-toxic by FHSA standards
- Non phytotoxic, must be inert
- Neutral Ph

Table 2.-- Comparison of "VITERRA" ROOT-DIP versus other super-absorbents.

SYNTHETIC SUPERABSORBENT MEASUREMENT TEST

National Tree Seed Laboratory
September 9, 1986

SCREENING FOR PARTICLE SIZE	ROOT-DIP	COMPETITOR
Sample	50 gr.	50 gr.
Over #20 screen	.19 gr. .3%	8.27 gr. 16.5%
Through #20 screen and over #40 screen	49 gr. 98%	35.75 gr. 71.5%
Through #40 screen (Dust)	.79 gr. 1.6%	5.89 gr. 11.8%
Lost in screening	.02 gr.	.09 gr.
ABSORPTION		
Superabsorbent Sample	.25 gr.	.25 gr.
Water sample	300 ml.	300 ml.
Hydrated Gel Particles	86.67 gr.	49.87 gr.
Excess Water Vacuumed off	205 ml	243 ml
Excess Water Lost in Filter	8.58 ml	7.38 ml
Absorption Rate	346:1	198:1
CHARACTERISTICS		
Particle Size	Excellent	Poor
Suspension	Good	Poor
Gel Strength	Soft	Hard
Water Absorption	Good	Poor

Dustless--Superabsorbent dust added to water can become a "coating." If this coating dries out, it can act as a barrier, sealing off oxygen to the roots.

Uniform particle size--In order to obtain (-20+35) a uniform, stable suspension, with sufficient hydrated granules, to adhere to the seedlings...when the granules are too large, they will fall off roots.

-Propenoate-propenamide copolymers with the correct rate of potassium polyacrylate and polyacrylamide.

-Absorption capacity should be no more than 400 times its own weight, and no less than 300 times.

-The absorption capacity and size of the granule determine the weight of the hydrated gel that clings to the roots.

-ROOT-DIP superabsorbent should be coated with hydrophobic adjuvant to avoid lumping during hydration.

-Should be easy to use.

-The physical-chemical properties of the ROOT-DIP gel should ensure that moisture is released from the gel to the roots when the moisture equilibrium of the roots need it. (diaper gels hold and retain water,

but do not release it)

-When dry, the ROOT-DIP gel looks like a white crystal. It is odorless, free flowing.

-When hydrated, the ROOT-DIP gel should not be rubbery or hard. To be sure that moisture can be released, gel should be on the soft side.

-Hard gels will fall off the seedlings during handling.

-The ROOT-DIP gel must be supported by good quality control and a company that is in the agricultural business, knowledgeable and responsive to grower needs.

10. THE FUTURE

The future of superabsorbents in forestry is bright.

The aim will continue to be to encourage governments, industry, and the public in general, to forest the land, to preserve it and enjoy it, and in so doing, to utilize safe proven products at an economical cost.

Our responsibility as nurserymen, is to be there and to utilize the best methods available to grow the best seedlings.

Organic Matter: Short-Term Benefits and Long-Term Opportunities¹

John G. Mexal and James T. Fisher²

Abstract: Crop benefits derived from organic amendments to southern nurseries appear minor and limited by the rapid rates of OM decomposition common to the region. This paper reviews a case study and related studies to examine the actual and potential benefits of amendments as determined by the kinds, amounts and frequencies of applications. It is possible to increase the stable fraction of OM in nursery soils and, potentially, to improve seedling growth and yield. However, it will be necessary to apply amendments more frequently than conventionally done.

INTRODUCTION

Nursery managers believe organic amendments are essential to efficient nursery production in southern regions. This belief is at least partially derived from the manner in which seedlings are harvested. In contrast to most agricultural crops, nursery seedlings are harvested as whole plants, and only negligible amounts of post-harvest crop residues remain in the soil.

Clearly, organic matter (OM) is essential for efficient crop production. It acts as a reservoir of nutrients that become available slowly as decomposition proceeds. In addition, OM improves soil cation exchange capacity (CEC). Consequently, more nutrients are retained against leaching in soils high in OM. OM also buffers the soil against abrupt changes in soil acidity that can occur when fertilizers such as ammonium sulfate are applied.

OM improves water infiltration and augments net soil moisture retention. These benefits are important for soils that tend to crust or that have high salt content, esp., sodium (DeBano, 1981). OM adsorbs the cations and prevents flocculation of clay particles. Certain types of OM can suppress soil-borne plant pathogens such as Pythium and Phytophthora through the release of fungicides. OM also can alleviate the symptoms of certain abiotic diseases caused by herbicides or excess salts.

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Nurseries apply a variety of organic amendments to maintain soil OM (Davey, 1984). In the South, conifer sawdust and bark are commonly applied because of the abundance of wood mill residue. Other OM amendments include

hardwood sawdust and bark, municipal waste and animal waste. Use of these materials is usually limited by local availability. For example, fish waste or horse manure is applied if the nursery is near a hatchery or racetrack, respectively. Transportation costs generally preclude nurseries from using northern peat moss.

Green manures or cover crops do not add to the stable organic fraction of the soil. In fact, when a cover crop is turned under, soil OM may actually decrease after a brief period (Pieters and McKee, 1938). Essentially, the stimulation of microbial activity created by the addition of a readily decomposable food supply can cause a net reduction in the steady state level of soil OM. However, cover crops are not without merit; they can be used effectively to reduce wind erosion and to eliminate plow pans.

Nursery soil OM depends on location and soil type. Nurseries in the Northwest tend to have OM levels greater than 3 % (Davey, 1984). However, nurseries in the South average less than 3 % soil OM (South and Davey, 1982) and those on sandy or sandy loam soils have less than 1.5 % OM. Nurseries in the Southwest (New Mexico and Oklahoma) average about 1 % (Myatt, 1980; Windle, 1980).

The objective of this paper is to discuss the short-term response of nursery soil to organic matter additions using the USFS Albuquerque Tree Nursery as a case study, and to discuss the long-term opportunities to improve crop production through better OM management in nurseries.

ORGANIC AMENDMENTS APPLIED TO A SOUTHWESTERN NURSERY: A CASE STUDY

Treatments

Before fumigation for the 1984 crop, approximately 12 mm of OM was incorporated into the surface 15 cm. The OM treatments included gamma-irradiated sewage sludge, pine bark, pine sawdust, horticulture grade peat moss and no OM. Treatments were added at the rate of 67 t/ha, except sawdust that was added at 43 t/ha. Soil and seedling nutrient status were

followed over the course of the production cycle (1.5 growing seasons), and seedling yield and morphology were determined November 1985.

Results

The OM additions caused immediate but short-term changes in soil OM and nutrient availability. Soil OM (particles < 2 mm) was affected most by sawdust (Fig. 1). The sawdust plots had an OM content of nearly 4 % about 2 months after application. Sludge increased OM less than 1.0 %. Particles > 2 mm were still visible in the soil, but these are not measured in standard OM determinations. In all likelihood, particles this large neither stimulate soil microbial activity nor directly influence seedling nutrition.

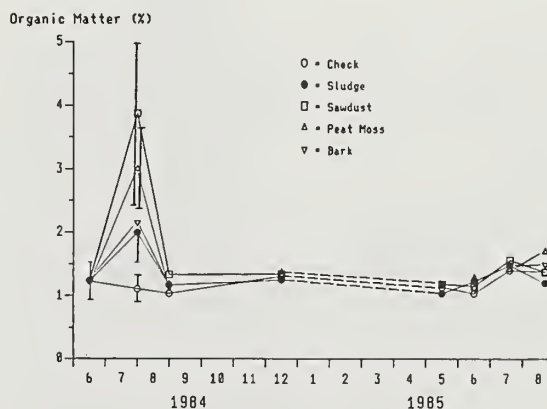


Figure 1.--Effect of organic amendments on soil test OM at the Albuquerque Tree Nursery. Only the peat moss treatment is significantly different from the control ($\alpha = .05$) for the July 1984 sample only. Vertical bars represent ± 1 S.E. of the mean.

The response of soil nutrients to OM was also short-lived. Only sludge increased soil NO_3 (Fig. 2A). Bark and peat moss had no detectable effect, but sawdust caused rapid immobilization of NO_3 . By August, NO_3 in the sawdust plots was 1 ppm compared to 28 ppm for the control. By December, all plots had only 1 ppm NO_3 . Five applications of urea (53 kg/ha) failed to increase soil NO_3 to more than 20 ppm, and by August 1985, soil NO_3 returned to 1 ppm, the pre-application level.

Other nutrients (P, K and Fe) behaved similarly (Fig. 2B-D). Generally, soil nutrient levels increased shortly after OM application, and decreased over the remainder of the rotation. For example, K decreased from 145 ppm before sowing to about 60 ppm 14 months later. Again, sludge increased soil K slightly early in the season, while sawdust decreased soil K slightly. Bark and peat moss did not alter nutrient levels. All treatment differences disappeared by December 1984.

OM amendments had no effect on seedling yield, height, caliper or fresh weight. However, seedling R/S was significantly reduced by bark, sludge and peat moss (Table 1). Seedling shoot fresh weight was positively correlated with increased soil nutrient levels brought about by the OM additions. However, R/S and shoot fresh weight were only slightly affected by OM addition. Nevertheless, the responses detected do indicate that OM amendments can alter seedling morphological development. However, additional work is needed to adequately explain this relationship.

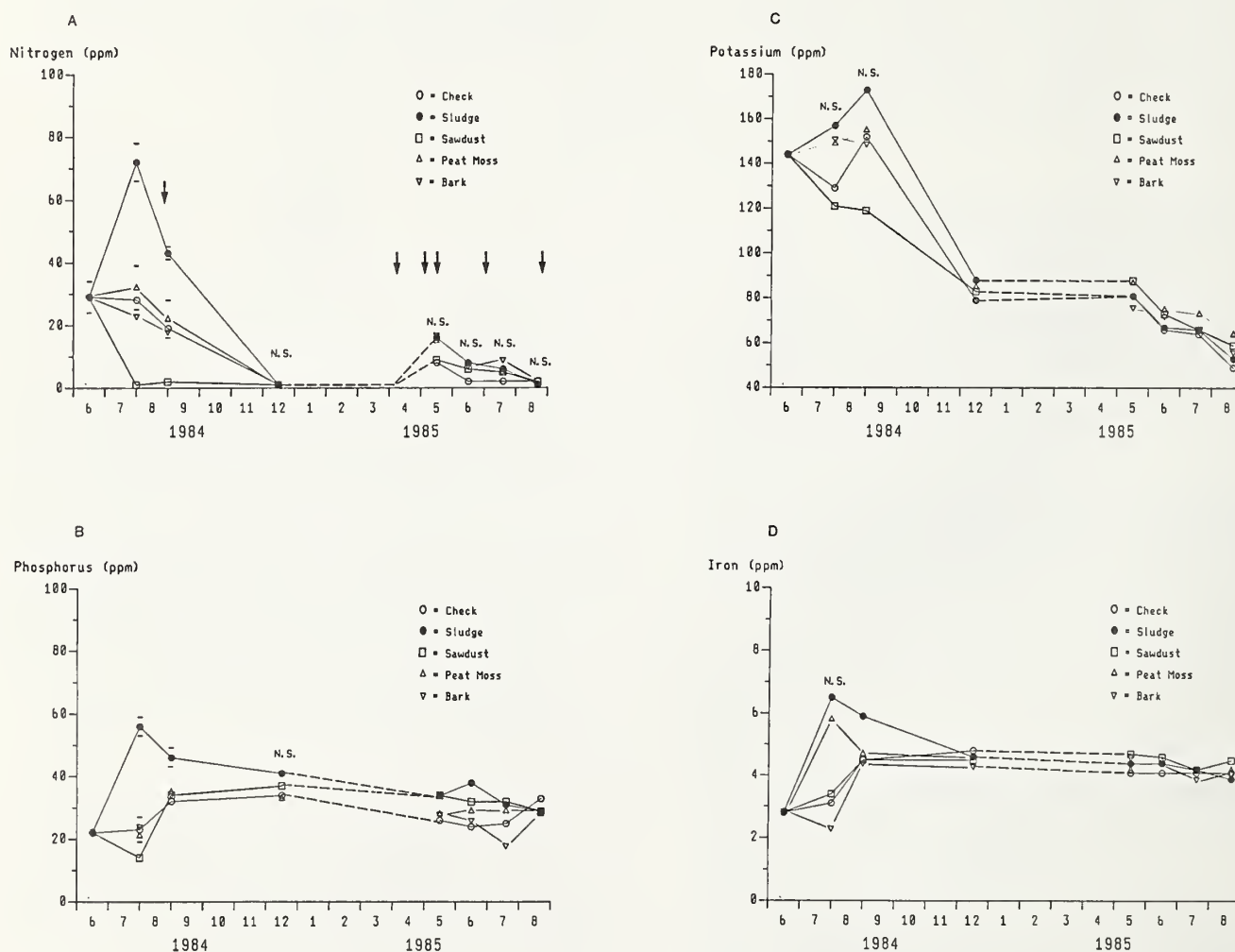


Figure 2.--Effect of organic amendments on soil test nutrient contents at the Albuquerque Tree Nursery, where A = nitrogen, B = phosphorus, C = potassium and D = iron. Arrows in Fig. 2A indicate applications of 53 kg/ha of urea. Vertical bars represent ± 1 S.E. of the mean; N.S. = not significant.

Table 1.--Effect of different organic amendments on 1.5 + 0 ponderosa pine seedling morphology.

Treatment	Height (cm)	Caliper (mm)	Fresh Weight(g)		
			Shoot	Root	R/S
CONTROL	10.5	3.4	3.84	1.94	.56
SAWDUST	9.7	3.4	3.59	1.74	.54
BARK	11.4	3.4	3.98	1.86	.51 ¹
PEAT MOSS	10.4	3.2	3.66	1.72	.51 ¹
SLUDGE	11.2	3.5	4.16	1.89	.50 ¹
	NS.	NS.	N.S.*	NS.	

¹ Significantly different from Control (d=.05)

* Correlated with Nov. 1985 Soil [P] and [N]

DISCUSSION

Although not encouraging, our results generally agree with studies conducted in the southern United States. Saloman (1953) treated soil with various levels of sawdust and found no change in soil OM and no improvement in plant growth. Similarly, the addition of sewage sludge to a nursery soil in the Northwest resulted in few improvements among the conifer species tested, and results from the outplanting trials were generally negative (Coleman, et al., 1986). However, Berry (1980) found that pine responded positively to the addition of sludge in a Florida nursery. Seedlings responded best to sludge applied at rates of 60-136 t/ha. The 67 t/ha treatments employed in our study failed to promote a similar response in ponderosa pine seedling growth.

Long-Term Opportunities

Many studies, including this one, examine the short-term response of soils, and generally report the response of one seedling crop to a single OM addition. Such studies point to the rather abrupt changes occurring in amended soils. Within 1 year, more than 60 % of the OM added will decompose, and about 90 % will be decomposed in 2 years or less (Davey, 1984). Davey and Krause (1980) believed the stable fraction of soil OM could be increased about 0.1 % by adding 20 t/ha. However, Munson (1983) found peat moss decomposed more readily as application rates were increased. Munson found OM levels in the soil would return to ambient levels in 28 months after the addition of 22 t/ha, and 34 months after the application of 90 t/ha (Fig. 3).

Organic Matter (%)

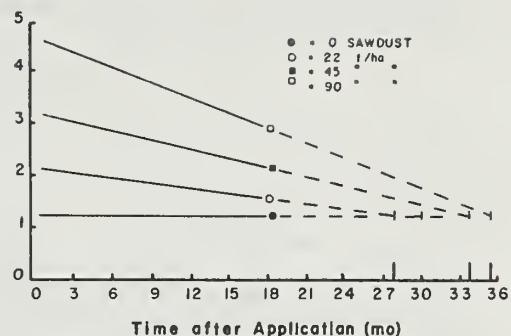


Figure 3.--Effect of rate of application on the decomposition of sawdust in a Florida nursery (after Munson, 1983). Return to ambient level is extrapolated to be 28 mo for 22 t/ha, 34 mo for 45 t/ha and 35 mo for 90 t/ha.

Apparently, amendments would have to be applied more frequently than once every 3-4 years to cause a net increase in stable soil OM.

A similar conclusion can be drawn from May and Gilmore (1984) who applied OM repeatedly in a loblolly pine nursery during a 6-year period. Sawdust was applied at 33 or 66 t/ha rates repeated two, three or six times over the course of the study. The maximum rate (66 t/ha applied every year) added a total of 396 t/ha of organic matter and effectively increased soil OM from 1.9 % to 3.2 % (Fig. 4). The OM level of the control plots was not altered over the 6-year period, despite the harvest of six seedling crops. Soil OM responded in a linear manner to the amount applied and to the frequency of application. The positive effects reported by May and Gilmore contrast sharply with studies employing single applications of comparatively large amounts of organic matter, and consequently reporting no practical benefits (e.g., Munson, 1982).

A relationship often ignored in the United States is the efficacy of inorganic fertilization as a substitute for organic amendments. Most information on this subject comes from the United Kingdom where the climate is much less severe than in the South or Southwest. Nevertheless, trials conducted in the United Kingdom have shown that inorganic fertilization can serve as a suitable replacement for OM.

However, in certain tests, the best treatment was a combination of inorganic fertilization and OM addition.

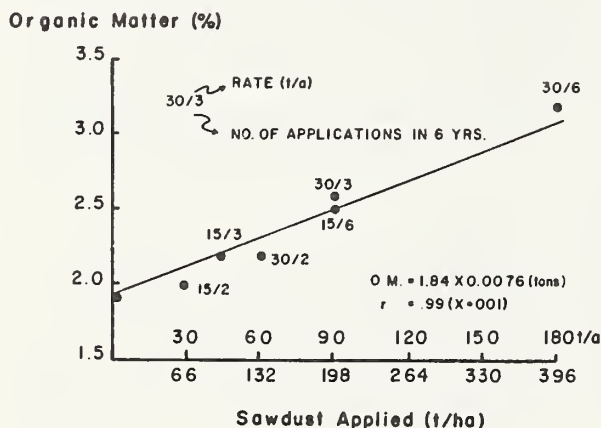


Figure 4.--Effect of amount and frequency of application of sawdust on OM content in a Alabama nursery soil (after May and Gilmore, 1984). The application rate was 16 and 33 t/ha applied either 2, 3, or 6 times in 6 years.

Future Prospects

Few studies have actually demonstrated that OM additions applied at conventional frequencies significantly improve nursery soils, seedling crops or profit margins. Present day practices will not significantly increase soil OM levels, and crop benefits will be of minor importance (see Fig. 4). More specifically, many nurseries apply 22 t/ha every 3 or 4 years before sowing 2+1 or 2+2 crops, respectively. Clearly, such practices will not significantly improve crop yield (Fig. 5). Within 4 years, the additional OM will decompose and will not cause a net gain in steady-state soil OM. Therefore, to significantly increase the stable OM fraction, at least 22 t/ha should be applied years 1 and 2 before sowing a cover crop.

Frequent applications of organic amendments will benefit some nurseries more than others. Among the problem soils potentially benefitting greatly

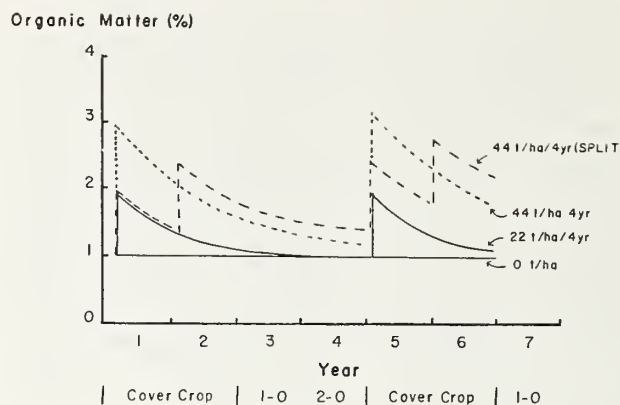


Figure 5.--Hypothetical trends in soil OM following different trends schemes of addition (adapted from Davey and Krause, 1980)

from frequent applications are those with comparatively low water infiltration rates. As seen in Fig. 6, OM level significantly affects water permeability. In the Southwest, the occurrence of torrential rains and the need to control evaporative losses are related concerns. OM should also increase soil nutrient retention and reduce the occurrence of crop maladies associated with salts and pesticides, as numerous studies of low-OM soils have shown.

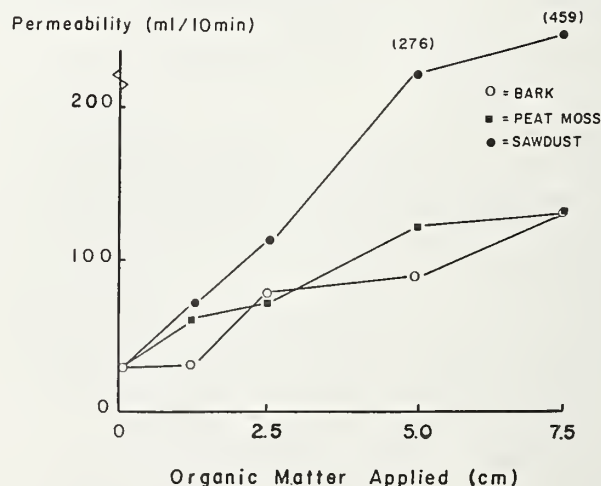


Figure 6.--Effect of type and amount of OM on water permeability (after Pokorny, 1982).

CONCLUSIONS

Extrapolations from our work and the study of May and Gilmore (1984) suggest that nursery soil OM can be raised to higher stable levels, even in regions where high temperatures and irrigation are conducive to rapid OM decomposition (Munson, 1982). Also evident is that present day amendment practices would have to be revised to provide the benefits desired.

Although OM amendments theoretically can improve nursery yield, field data for this region are inadequate to confidently predict economic benefits. For the present, we recommend nurserymen in the South and Southwest either apply no OM, or at least 2 applications of 22 t/ha over a 4-year rotation. Additionally, nursery managers should not overlook the opportunity to add OM before sowing the seedling crop, or the benefits derived from mulching with organic materials such as bark.

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The Trees Unlimited Program: An Experiment in Establishing Seedling Plantings¹

Robert C. Oswald²

Abstract.--Trees Unlimited is a pilot project formed in 1985 to provide an integrated, year-round program of planting design, seedling planting, and maintenance to rural landowners in northern Colorado. It is a nonprofit program which sells seedling survival products and total tree care services associated with the establishment of conservation plantings.

INTRODUCTION

Trees Unlimited was formed in 1985 through funding by an association of four soil conservation districts in the northern front range area of Colorado and the State Soil Conservation Board. The intent was to provide not only promotion and sales of seedling trees in the area but also to provide to the rural landowner a source of planning and design assistance, site preparation, planting, and other tree care services associated with the establishment of seedling conservation plantings.

The program operation is similar to that of a small business. Although it is nonprofit, it must generate its own operating budget. Therefore, there is a fee charged for services besides the price of goods and materials sold.

ORGANIZATION

Trees Unlimited is overseen by a board consisting of a member from each of the four soil conservation districts involved. There is a program manager who reports the progress periodically to the board but operates the program mostly autonomously.

Cooperating with the program are the local field offices of the Colorado State Forest Service (CSFS) and the USDA Soil Conservation Service (SCS). These offices actively refer interested parties to Trees Unlimited. These same district offices also help support the program through lending field assistance, office and storage space, and seedling storage facilities during the spring.

¹Paper presented at the Intermountain Nursery Association Meeting, Oklahoma City, Oklahoma, August 10-14, 1987.

²Robert C. Oswald is the Tree Program Manager of Trees Unlimited, Longmont, Colorado.

The original targeted market for sales of seedling conservation plantings was the large number of agricultural producers in the area. However, due to various factors, the majority of plantings sold during the last two years has been to owners of small rural acreages. Because the area is situated near several population centers, there is an abundance of the "hobby farms" in the 1,500 square miles that Trees Unlimited serves.

PLANTING SERVICES

Trees Unlimited tries to make available a wide variety of products and services for its customers. Various combinations of materials and services are needed in each different situation, and assistance is given to the landowner to decide which practices and plants are appropriate or needed. In these seedling plantings, the plant material is typically a small percentage component of the total program cost. Overall, labor costs are the largest portion, followed usually by cost of drip irrigation materials. Some representative prices of services are shown in table 1.

The program manager will perform an initial site visit and landowner consultation, design a planting and/or irrigation plan, offer several site preparation and weed control methods, and detail all of these prices in an itemized bid. Based on the landowner's budget and the need/desire for a planting, he or she will decide on the size of planting and level of service to be implemented.

Upon signing the contract agreement and receipt of the initial payment (depending upon the season), work can begin immediately. Actual installation of tree shades can be seen in figure 1.

The types of conservation plantings Trees Unlimited has implemented include field and farmstead windbreaks, wildlife habitats, Christmas tree plantations, and fruit orchards. The designs conform to SCS and/or CSFS specifications.

Table 1.--Average prices charged to planting customers based on a planting of 200 to 300 trees and shrubs.

Services and products	Price charged per tree ¹
Site visit	0
Planting and/or irrigation design (total)	75.00
Site preparation--Simazine application	1.10
Site preparation--Rototilling	.80
Plow & disk (CSFS rented equipment)	1.80
Planting (manual or by machine)	1.25
Fertilizer tablet, installed	.25
Plastic rabbit guard, installed	.80
Wooden tree shades, installed	.80
Drip irrigation system, installation	1.00
Drip irrigation system, materials ²	2.20
Wood chip mulch, installed	1.10
Polypropylene mulch, installed	3.90
Herbicide application, Roundup	.50
Insecticide spray	.40

¹These prices are the base amount for work within a 20-mile radius of Ft. Collins or Longmont, Colorado. For each 10 miles beyond the radius, the base price is increased 20%. These prices are for services to seedling plants.

²This is an estimate based on actual amounts of materials used on past plantings; used here for preliminary estimate.



Figure 1.--Installation of wooden tree shades on a 3-row windbreak near Boulder, Colorado.

Another important form of conservation in Colorado is water conservation. On a tree planting great amounts of water (plus time, water costs, and pumping costs) can be saved through employing a drip irrigation system. Trees

Unlimited stocks a full line of materials for sale and installation. This accounts for a large percentage of material sales annually.

Providing these services on most of the plantings has yielded survival rates, on an average, of greater than 95% into the second year. An example of a high level of service, i.e., combining several products to contribute to seedling survival, can be seen in figure 2.



Figure 2.--Close up of a pinyon pine seedling, showing plastic rodent guard, tree shade, drip irrigation pipe, and wood chip mulch.

PROGRAM PROMOTION

Trees Unlimited has a small advertising budget and relies in large part on the cooperating agencies' active referrals for business. The program also utilizes press releases and news announcements through the local radio stations and newspapers. Booths at country fairs shared with soil districts have helped for exposure. The soil districts and agency district offices also keep Trees Unlimited's brochures to hand out. Mass mailing to targeted areas, telephone contacts, and site visits make up most of the winter duties.

INVOLVEMENT WITH NURSERIES

Trees Unlimited contracted for planting almost 8,000 seedling trees in 1987, both bareroot and containerized. The bulk of these were purchased from the CSFS Nursery in Ft. Collins,

Colorado. Most seedlings sold by this nursery are either picked up by the customer on specific days or shipped out during a short time period each spring. With a schedule such as this, it might be inconvenient, if not impossible, for a program such as Trees Unlimited to interact with a nursery if the nursery policy were inflexible. Due to the nature of Trees Unlimited's business, planting time is extended, usually filling all of April and May. The trees must be stored during that period, yet be available to the planter every day. A workable arrangement has been made for storage and pickup, both from the nursery and from a CSFS district office 50 miles away, which provides similar storage facilities.

Other seedling survival products and chemicals are often purchased through a few of the local commercial nurseries.

Occasionally, larger planting stock is desired by the customers, and that is available everywhere. For the most part, the seedling-size planting material has the best combination of

hardiness, vigor, size, ease of planting, and affordability.

THE FUTURE

As all of the people involved with Trees Unlimited agree, this is a program which is valuable and necessary in this area. It fills an important niche, providing the link between the seedling producer and consumer. It is a new program and will continue to depend on all of the involved parties to promote it. It is not a well-known name yet, and most potential customers do not know such a program exists. For that reason, it is felt that if this type of "total tree care" program were to be initiated in any certain area, it had best be allied in some way to an existing, known channel or outlet of seedlings. Publicity is usually the limiting factor to growth of a worthwhile business, and the cooperation and support of the area agencies are essential to the success and growth of such an experimental program.

The Potential of Soil Solarization in Nurseries to Control Soilborne Diseases¹

Kenneth E. Conway^{2,3}

Abstract.--Use of clear polyethylene sheeting to heat soil, through the technique called soil solarization, is being evaluated as a method to control soilborne pathogens at the Oklahoma Division of Forestry Nursery and at Stillwater, OK. Studies are directed at the effects of solarization on population densities of *Pythium* spp., *Macrophomina phaseolina*, and *Sclerotium rolfsii*. Soil temperatures under polyethylene sheeting during August-September at the Stillwater location reached maxima of 10 to 12 C greater than bare ground controls.

INTRODUCTION

Soilborne diseases incited by several genera of fungi can be economically destructive in a forest nursery. Pathogens of particular importance in Oklahoma are: *Fusarium* spp., *Pythium* spp., *Rhizoctonia solani*, *Sclerotium rolfsii*, and *Macrophomina phaseolina*. Techniques used to control these pathogens have included crop rotation, fungicides (seed treatments, broadcast applications, and drenches), and soil fumigation. Each has its limitations due to the wide host range of soilborne pathogens, environmental contamination, or economics. The use of thin, clear polyethylene sheeting to transfer solar energy to soil to increase soil temperature is an alternative technique that needs to be investigated for use in the nursery.

This technique is called soil solarization and is based on our knowledge of thermal inactivation of soilborne organisms (Table 1). A 30 minute exposure to temperatures of 66 C will destroy most pathogenic bacteria and fungi. Pullman, et al. (1981) explored the relationships between increased temperatures and length of exposure to those temperatures on the survival of several soilborne fungi. Temperatures of 37 C for 18-28 days were needed to reach LD₉₀ levels (90% reduction in populations) for *Pythium ultimum* and *Verticillium*

dahliae. However, when temperatures were increased to 50 C, LD₉₀ levels were achieved in 27-33 minutes. Therefore, lower temperatures can reduce populations of soilborne pathogens, but longer exposure times will be necessary.

Maximum soil temperatures of 60 C have been reported at depths of 5 cm in soil using solarization (Pullman, et al. 1981). However, these maxima are attained for only short periods of time. Reduction of population densities of soilborne pathogens is more realistically achieved by increasing soil temperatures 5 to 10 C above normal for an extended period of time. The effect of solarization on soilborne pathogens is a chronic effect that weakens and debilitates the survival structures (conidia, sclerotia, etc.) of these fungi. Other soil organisms are more thermo-tolerant and are not affected by solarization. These residual organisms multiply and prevent the recolonization of soil by the pathogen after solarization.

Table 1.--Temperatures required to inactivate pests in compost soils^a

Pests	Temperatures ^b	
	(F°)	(C°)
Nematodes	120	49
Damping-Off Organisms	130	54
Most Pathogenic Bacteria and Fungi	150	66
Soil Insects and Most Viruses	160	71
Most Weed Seeds	175	79
Resistant Weeds and Viruses	212	100

^aModified from Baker and Cook, 1974

^bTemperatures maintain for a minimum of 30 minutes

Soil solarization has been used successfully

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to control a number of pathogens in various cropping systems (Conway, et al. 1983; Grinstein, et al. 1979; Jacobsohn, 1980; Katan, et al. 1983). Other research has indicated control of nematodes, weeds, and growth enhancement of crops planted in solarized soil (Heald and Robinson, 1987; Jacobsohn, et al. 1980; Grinstein, et al. 1979; Stapleton and DeVay, 1984). There have also been studies in which control of soilborne diseases was not achieved, particularly for Macrophomina phaseolina (McCain, et al. 1982; Mihail and Alcorn, 1984). Charcoal root rot, incited by M. phaseolina, has been a severe problem in southern tree nursery production. Unfortunately, reports on the use of solarization in forest nurseries are very limited. Hildebrand (1985a, 1985b) used soil solarization to reduce levels of Pythium and Fusarium spp. and weed seeds in Colorado and Nebraska forest nurseries. She estimated that, compared to chemical fumigation, solarization saved approximately \$350.00/A in production costs.

In order to evaluate soil solarization as a technique to control soilborne diseases, experiments were initiated in 1986 at the Oklahoma Forestry Division Nursery at Washington, OK, by Mr. Mark Miles, a graduate student in the Department of Plant Pathology at Oklahoma State University. Additional experiments were performed at Stillwater, OK. Although much of this work is preliminary and will be used for Mr. Miles' M.S. thesis, a generalized overview of the research is presented below.

METHODS

Previous work (Conway, unpublished) has indicated that Pythium irregulare and Fusarium spp. were the primary soilborne pathogens at the Forest Nursery. Recently, stunted sycamore and Virginia pine seedlings were removed from the Nursery and isolations from the roots indicated that M. phaseolina was also an active pathogen. At Stillwater, populations of Sclerotium rolfsii and M. phaseolina have been documented in our apple seedling nursery (Conway and Tomasino, 1987; Tomasino and Conway, 1987). To ascertain the effectiveness of solarization, populations of Pythium spp. and M. phaseolina at the Forest Nursery, and of S. rolfsii and M. phaseolina at Stillwater will be enumerated before and after solarization.

Solarization experiments were performed at the Forest Nursery during April-May 1986 and August-September 1987. Experiments at Stillwater were conducted during August-September 1986 and 1987. In 1986, temperature data were collected through use of a system developed by Dr. V. Pederson, North Dakota State University. The computer program was modified to allow for 22 separate temperature probes.

Prior to placement of the polyethylene sheets, soil samples were randomly removed from all plots and stored at 4 C. Soil was bulked and thoroughly mixed before subsamples were removed.

Population densities were determined for Pythium spp. and M. phaseolina using selective media (Conway, 1985; Campbell and Nelson, 1986). At Stillwater, spun-bound polyester packets containing 50 sclerotia of S. rolfsii were placed at 0, 5, 10, and 15 cm depths in soil to be solarized or used as controls. All soils were moistened prior to solarization. At Stillwater, drip irrigation was installed beneath the polyethylene sheets. Temperature probes were buried at 2, 4, 12, and 20 cm depths in soils of both solarized and control plots. The computer was programmed to record input from each probe every 30 minutes. Polyethylene sheets (4 mil thick) were applied to the plots using a mulch-laying apparatus. Appropriate sections of the polyethylene sheet within the row were removed to provide for control plots. Solarization lasted for approximately 6 weeks and soil samples were, again, randomly collected to determine densities of selected pathogens. Packets containing sclerotia of S. rolfsii were also removed, at that time, and percent viability was determined.

RESULTS AND DISCUSSION

Weather during April-May 1986 at the Nursery was unusually cloudy and greater than average precipitation occurred. On clear days, soil temperature at a depth of 4 cm in solarized plots reached 49-50 C with a daily average of only 4 hr during which temperatures were greater than 37 C. Nonsolarized soils at the same depth attained temperatures of only 24-32 C. Population densities of selected fungi have been determined but differences among treatments have not been analyzed.

At the Stillwater location during August 1986, solarized plots reached temperatures of 57 C, with 6 to 7 hr greater than 45 C, at 4 cm depths. Non-solarized soils reached a maximum of 45-46 C. Packets containing sclerotia of S. rolfsii were retrieved from the soil after 4 weeks. Viability of sclerotia was determined by placing sclerotia on moistened filter paper in petri dishes and observing germination. No significant differences in viability between solarized and non-solarized soils were found at that time.

Soil solarization will not be a panacea for all nursery problems related to soilborne fungal pathogens, nematodes and weed seeds. Problems of polyethylene residue are similar to those involved with the use of chemical fumigants. Another concern is that soil solarization may not be effective in reducing population densities of particular fungi, such as Macrophomina phaseolina. In order to study this further, we have initiated laboratory experiments to determine the thermal death points in soil of Pythium irregulare isolated from the Nursery and isolates of M. phaseolina from several different hosts. Analysis of these data will enable us to make predictions regarding the effectiveness of solarization in the control of these pathogens.

To improve the effectiveness of soil solarization, future research should involve the integration of solarization with biological control agents (Elad, et al. 1980), the use of crop residue amendments (Ramirez-Villapudua and Munnecke, 1987), and the use of ammonia-based fertilizers. Data should be collected on the total effect of solarization and should include reductions in pathogen (including nematodes), weed and insect population densities.

Although our work is preliminary, we feel that we are in an exciting area of research, one that may have very real benefits for nursery production and management.

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Seedling Production at Oklahoma Forestry Division Forest Regeneration Center¹

Clark D. Fleege²

The Oklahoma Department of Agriculture's Forestry Division has been supplying tree seedlings for conservation plantings since 1927. The Forest Regeneration Center near Goldsby distributes 4 - 4½ million seedlings annually. This includes bareroot one year old hardwoods, bareroot one and two year old conifers. The Division also manages a southern pine seed orchard.

The Oklahoma Forestry Division has been growing and distributing tree and shrub seedlings for Oklahoma's private landowners for almost as long as it has been in existence. From a meager beginning at Stillwater (in northcentral Oklahoma) in 1927, Oklahoma's State Tree Nursery moved first to Stringtown in 1938, and then to its present location south of Norman in 1945.

The Forest Regeneration Center at Washington produces hardwoods and conifer seedlings. It was formerly one of two nurseries operated by the Forestry Division. From 1949 until 1977, the Division grew southern pine seedlings at its nursery in southeast Oklahoma. Because of the need for modernization, and the high cost of operating two nurseries, a decision was made to contract the production of southern pine seedlings to the Weyerhaeuser Company nursery in southeast Oklahoma.

The purpose of the Regeneration Center is to provide Oklahoma's private landowners with quality tree and shrub seedlings for planting on their lands. These seedlings are sold state-wide for a variety of purposes. Including wildlife habitat improvement, wind-break establishment, fuelwood, postlots, erosion control plantings, Christmas trees and timber production.

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The Regeneration Center had 65 acres under production. Currently we produce 20 species of hardwoods and 9 conifer species. Our annual production is 4 to 4½ million seedlings. Currently the Forestry Division contracts with Weyerhaeuser to produce one year old improved loblolly pine seedlings. We also contract with Colo-Hydro of Longmont, Colorado for the production of conifer tublings used for planting on selected shallow, droughty soils of western Oklahoma.

The soil is a sandy loam "second-bottom land" soil, slightly basic. Each year we have soil samples analyzed through the State University of New York and amend each field accordingly to reach optimum nutrient levels for seedling production. For example, we will add sulfur to lower ph on specific fields; and manure and sawdust on every field to raise organic matter and improve soil texture. Fields that are not in crop production are planted to sudan grass cover crop in the spring. The cover crop will be mowed regularly throughout the growing season. Prior to winter the cover crop will be plowed and the field will be prepared for a spring planting. Generally, we have a field in cover crop every other year. We have two wells that pump to a 210,000 gallon storage tank from which all field irrigation is pumped. The entire nursery can be irrigated through a network of underground mainlines and field groundlines.

The seed for producing our crop is either collected from proven quality local Oklahoma sources; or purchased from reputable seed dealers, source-identified.

We have been working closely with the Soil Conservation Service/Plant Materials Centers and Oklahoma State University in identifying those varieties that will exhibit specific traits deemed desirable, such as faster growth rate, drought-tolerance, frost-hardiness, disease-resistance, etc. Several varieties have been identified and seed production areas of those varieties have been established near the Regeneration Center. All seed is processed and stored at the seed extraction building.

All the hardwood species we produce are one year old seedlings. Seven species are fall or winter sown, and the remainder are stratified and planted in the spring. Because of our longer growing season, some species can become quite tall. For example it is more the rule than the exception for black locust sown in mid-June to be seven feet tall by October with little if any irrigation or fertilization. Of the nine species of conifers we produce, six are spring sown, two year old seedlings. Through fumigation and proper soil management we anticipate producing our improved Virginia pine and limited quantities of improved loblolly pine in just one season. The remaining conifer, bald cypress, can easily reach plantable size in one season. Immediately after the beds are sown, we apply a light layer of fine sawdust followed by a layer of hydromulch. This is done to help retain soil moisture, reduce soil temperatures and prevent "wash-out" in the event of severe spring showers.

Weeds are fierce competitors for soil moisture and nutrients. We try to maintain a weed-free nursery through the use of registered herbicides, mechanical weeding machines and seasonal labor. Over the past 10 years we have been working with State University of New York and Dr. Larry Abrahamson in testing those herbicides that will control weeds and not effect seedlings. The effort has produced outstanding results; we have 90% of our tree species under chemical-weed control. The program is still on-going for those newly acquired species. Regularly when the seedlings are 4-6 inches in height, we will use a mechanical brush hoe to control weeds in seedbeds.

Not only are weeds controlled, but an additional benefit is the break-up of the soil crust in the seedbed. Our last line of defence in the great weed wars are seasonal personnel, armed with hoes, weeding knives and/or round-up herbicide applicators. During the course of the summer our temporary crew numbers 5-7 people.

A comprehensive lateral root pruning and root wrenching schedule is followed to develop fibrous root systems of conifers and hardwoods for improved outplanting survival.

The seedling harvest season at this nursery begins late November/early December and ends mid- to late March. Winters in Oklahoma tend to be wet and cold with occasional snow. Usually in January we experience a two to three week freeze and all harvesting comes to a halt. After that time the ground thaws and harvesting resumes. In the past a Grayco Seedling Harvester was used to lift the seedlings; now we use exclusively Fobro lifters. All seedlings are processed and counted before shipment. The seedlings are graded as per accepted industry standards for height and caliper, grouped into 50's and machine-tied. A heeling-bed is used for temporary storage of hardwoods. The seedling cooler is used for storing remaining hardwoods and all conifers. The temperature of the cooler is 34 degrees and the relative humidity is 100%.

The majority of our tree sales are to small rural landowners; average order size is about 500 seedlings. Cooperators will receive their seedlings packages either through the United Parcel Service (UPS), or by picking them up at the nursery. Friday is the designated pick-up day and those that are included are notified a week in advance. This method of using UPS to ship seedlings and the one designated pick-up day/week is quite effective.

For the past two seasons, with the cooperation of the Soil Conservation Service and the State Conservation Commission we have located numerous seedling distribution sites in communities statewide. By distributing the seedlings directly to the landowners from our refrigerated seedling trucks, we hope for greater out-planting survival.

Annually Forestry Division service foresters will conduct comprehensive seedling survival investigations at numerous planting sites statewide. This information will be used to help evaluate the cultural practices used for producing seedlings at the nursery. We feel these survival studies are necessary for the continued production of quality seedlings. Service foresters also assist in seed location and collection. They develop and help implement planting plans for rural landowners. Our service foresters serve as a valuable extension of the Regeneration Center.

The Forestry Division manages a genetically improved southern pine seed orchard in southeast Oklahoma. We are utilizing the advancing front concept which involves the most productive families currently available. The initial orchards were established in the mid-60's and currently coming into full production. This provides the landowners of Oklahoma with the only available local source of genetically improved loblolly and shortleaf pine seedlings which have been thoroughly field tested through progeny tests to determine the most productive sources.

These seedlings will give higher yields of high quality timber in a shorter amount of time than "woods run" seedlings. The Division is a member of Western Gulf Forest Tree Improvement Program (WGFTIP). This is a cooperative whose members include other state and private organizations interested in the genetic improvement of forest trees. Currently 100% of all shortleaf and loblolly pine distributed by the Division is genetically improved. Through

continued research and testing with WGFTIP and Oklahoma State University, the Oklahoma Forestry Division will continue to provide the very best planting material available to the landowners of Oklahoma.

Through proper soil management, timely and appropriate cultural practices and quality control, we are ensuring the continued production of quality tree and shrub seedlings for conservation plantings in Oklahoma.

Priming Treatments to Improve Pine Seed Vigor¹

S. W. Hallgren²

Abstract.--Osmotic priming improved both final germination and rapidity of germination in loblolly pine and showed a detrimental effect or no effect on slash pine seeds. The beneficial effects of priming were lowest for stratified seeds and greatest at a low germination temperature.

INTRODUCTION

Nursery managers prefer to work with high-vigor seed lots that show rapid uniform germination and produce vigorous seedlings under a wide range of conditions. Seedling costs are lower because there are fewer culls and uniform stands of seedlings are easier to manage. Thus, there is a strong incentive to improve techniques for controlling and manipulating seed vigor.

Seed priming has shown promise as a technique for improving seed vigor in numerous agricultural and horticultural species (Heydecker and Coolbear 1977, Heydecker et al. 1973). The technique has been used to improve germination in cold soils (O'Sullivan and Bouw 1984, Sachs 1977), to alleviate thermodormancy (Valdes et al. 1985, Guedes and Cantliffe 1980) and to increase rate and uniformity of crop emergence (Heydecker and Coolbear 1977, Heydecker et al. 1973, Holley et al. 1984). Seeds are imbibed in an osmoticum that allows all the processes of germination to proceed to completion except radical emergence. The treatment is long enough to bring all the seeds to the same point, poised just before the last step in germination. Upon termination of the treatment, seeds are introduced to water and the germination process proceeds rapidly to completion (Bewley and Black 1985).

Previous work on priming required rather cumbersome techniques for bringing the seed in contact with the osmoticum that worked well for small quantities of seed (Heydecker and Coolbear 1977). Recently, a seed priming system was developed at Oklahoma State University that proved to be effective in priming vegetable seeds and could be upgraded to handle large quantities of seed. Basically, seeds are primed in columns of osmoticum that are vigorously aerated to insure adequate gas exchange for the seeds (Akers and Holley 1986, Akers et al. 1984, Holley et al. 1984).

This system was tested with loblolly (*Pinus taeda* L.) and slash pine (*Pinus elliotii* Engelm.) seed and the results were promising. Some of the preliminary results are presented here. A more complete evaluation of the technique is being prepared for publication in a scientific journal.

MATERIALS AND METHODS

Seeds used in the study were from single bulk lots of improved loblolly pine and slash pine collected in 1985 and supplied by the Texas Forest Service. Prior to priming the seeds were divided into two equal groups, one to remain in cold storage and one to receive a cold moist stratification treatment for 53 days.

The seeds were primed in transparent columns of vigorously aerated priming solution at 25°C (Akers and Holley 1986). The solutions were prepared from polyethylene glycol, molecular weight 8000, and water to have a water potential of -1.0 MPa. Each column contained 300 ml of solution and 400 seeds. Solutions were changed daily at first and every other day later in the 11 day treatment period. Light was not excluded from the priming columns. One

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group of seeds was not primed and was given an additional 11 days of stratification for a total of 64 days.

Following 11 days of priming the seeds were washed and divided into groups to be placed in two germinators, one at constant 25°C and another at 15°C. At 25°C the temperature is near optimum for germination of the southern pines and 15°C is considered stressful (Association of Official Seed Analysts 1981, Dunlap and Barnett 1984). The seeds received natural lighting during germination. The seeds were arranged in 4 replicates of 50 seeds on moist filter paper and the layout was a randomized complete block design in each incubator.

Germination was counted for 37 days, everyday at first and less frequently as germination slowed. A seed was considered germinated when the growing radical began to show geotropic curvature (Dunlap and Barnett 1984). Analysis of variance and the Least Significant Difference were used to determine the significance of treatment effects on final percent germination and the number of days to reach 50 percent of the final total germination (Steel and Torrie 1980).

RESULTS

The effect of priming on final germination for loblolly pine at 25°C was an increase of nearly 50 percent for unstratified seeds and no change for stratified seeds (Table 1). Days to 50 percent germination was reduced by more than 50 percent by priming for both stratified and

Table 1. Effects of priming on final percent germination and days to 50 percent germination for stratified and unstratified loblolly and slash pine seeds germinated at 25°C.

	Final Percent Germination		Days to 50% Germination	
	Stratified		Stratified	
	No	Yes	No	Yes
<u>Loblolly Pine</u>				
Not Primed	153 b	96 *	8.6 a	4.6 a *
Primed	79 a	96 *	3.1 b	2.0 b
<u>Slash Pine</u>				
Not Primed	88 a	92 a	4.8	3.8
Primed	72 b	66 b	4.4	3.6

¹For each species and stratification treatment means followed by the same letter are not different at the 5 percent level; * = stratification treatment significant at the 5 percent level.

unstratified seeds. Stratification alone increased final germination by 80 percent and reduced days to 50 percent germination by nearly 50 percent.

In contrast, slash pine final germination at 25°C showed a reduction due to priming of 18 and 28 percent for unstratified and stratified seeds. Stratification alone had no effect on percent germination and neither stratification nor priming affected days to 50 percent germination.

At 15°C loblolly pine showed only 2 percent germination when unprimed and unstratified (Table 2). Final germination was increased by stratification to 89 percent and by priming to 35 percent, and priming had no effect on stratified seeds. Days to 50 percent germination for stratified seeds was reduced by 60 percent by priming.

Table 2. Effects of priming on final percent germination and days to 50 percent germination for stratified and unstratified loblolly and slash pine seeds germinated at 15°C.

	Final Percent Germination		Days to 50% Germination	
	Stratified		Stratified	
	No	Yes	No	Yes
<u>Loblolly Pine</u>				
Not Primed	12 b	89 *	-	13.4 a
Primed	35 a	93 *	8.1	5.4 b
<u>Slash Pine</u>				
Not Primed	40	88 a *	13.2	11.3
Primed	35	44 b	12.4	13.4

¹For each species and stratification treatment means followed by the same letter are not different at the 5 percent level; * = stratification treatment significant at the 5 percent level.

The effect of priming on percent germination for slash pine at 15°C was nil for unstratified seed and a 50 percent reduction for stratified seeds. Stratification alone more than doubled percent germination. Days to 50 percent germination was unaffected by both priming and stratification.

DISCUSSION

The results of this study demonstrated that osmotic priming improves the vigor of loblolly pine seeds (Table 1 and 2). Osmotic priming is known to have beneficial effect on

the vigor of seeds of many agricultural crops (Heydecker and Coolbear 1977). There has been very little work done with tree seeds.

Osmotic priming, like stratification, can improve both final germination and rapidity of germination. The beneficial effects of priming are less if the seeds are stratified before priming, indicating that both treatments may affect some of the same germination processes.

The beneficial effects of priming for loblolly pine were even greater at a low germination temperature than at a nearly optimum temperature (Table 2). These results are consistent with findings for agricultural crops that priming can improve germination at suboptimum temperatures (O'Sullivan and Bouw 1984 and Sachs 1977). Apparently loblolly pine seeds are especially sensitive to low temperature stress during germination (Dunlap and Barnett 1984) and osmotic priming can be a practical option for overcoming the sluggish germination at low temperatures.

The results presented here are inconsistent with the previous findings that osmotic priming improved germination of slash pine seeds (Haridi 1985). The two studies are not entirely comparable since different techniques were employed and the priming treatment ran for nearly twice as long in the current study as in the prior one. There were many ways the techniques used in the current study could be adjusted to meet the needs of different species including changes in temperature, solution concentration, oxygen levels, types of osmoticum and length of treatment.

It is well known that loblolly pine and slash pine have different stratification requirements for removal of dormancy and it is not surprising that they show different responses to the same osmotic priming treatment (Krugman and Jenkinson 1974).

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Effects of Nursery Density on Shortleaf Pine¹

John C. Brissette and William C. Carlson²

Abstract.--A technique to determine the effective nursery bed density of individual seedlings was developed and then used to evaluate density influence on shortleaf pine (*Pinus echinata* Mill.) bare-root seedlings. At lifting, mean height had increased while mean root collar diameter and root volume had decreased with increasing effective density. After the first growing season, seedlings produced at lower effective densities exhibited greater height and diameter growth than seedlings grown at higher effective densities.

INTRODUCTION

Shortleaf pine (*Pinus echinata* Mill.) is the most important species used for artificial regeneration on the Ouachita and Ozark National Forests (Kitchens 1987). Approximately 12 million seedlings are planted annually on about 7,000 hectares of the two forests. Although artificial regeneration of shortleaf pine represents a large investment on the two forests, success of the program has been limited by poor seedling survival and growth. Excluding the severe drought year of 1980, seedling survival has averaged about 50 percent since large-scale planting was begun in the 1970's. The reasons for poor seedling performance are not clear. The planting sites are harsh, the soils are rocky, and the south and west aspects are exposed to hot, droughty conditions throughout the summer. However, many forest managers do not think that difficult site conditions alone explain the poor seedling performance. They note that seedling quality also must be considered. Consistent production of quality planting stock requires a thorough knowledge of seedling development in the nursery and an understanding of how nursery culture impacts field performance.

In a recent review, Barnett and others (1987) found few references to shortleaf pine stock quality. Two of the most enlightening items were by Chapman (1948) and Clark and Phares (1961).

The earlier paper dealt with the effects of morphological characteristics on the survival and initial growth of seedlings planted on old field sites in Arkansas, Missouri, Indiana, and Ohio. The later paper dealt with survival and growth of the plantations in Missouri and Indiana at age 19 and 20. In general, larger diameter seedlings performed better initially, and that early superiority was maintained over time.

One of the most critical factors determining seedling quality is seedbed density. Density is a measure of competition among seedlings for growing space and relates to their ability to receive light, water, and nutrients. As density increases, yield of cull seedlings increases and average root collar diameter decreases (Shoulders 1961). Seedling weight also decreases with increasing density. In loblolly pine (*P. taeda* L.), root weight is reduced proportionately more than shoot weight, resulting in a corresponding decrease in root-to-shoot ratio (Harms and Langdon 1977). Mexal (1981) concluded that the biological optimum density for growing loblolly pine seedlings is 200/m².

With the mechanical sowing methods in use, and less than perfect germination, nursery bed density is seldom uniform. Although bed density is a useful criterion for evaluating average seedling characteristics on a plot basis, bed density consequence on individual seedlings is difficult to determine.

In 1985 a study was established at Weyerhaeuser Company's Magnolia Forest Regeneration Center in southwest Arkansas to address the quality of shortleaf pine planting stock used to reforest Ouachita and Ozark Mountain sites. The effects of nursery bed density and fertilization on the morphology, nutrient status, and root growth potential of seedlings from that

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study were reported previously (Brissette and Carlson 1987). Objectives of this paper are to describe a method of determining the effective density of individual seedlings and to compare the morphology and subsequent first-year field performance of seedlings grown at a range of effective densities.

MATERIALS AND METHODS

This study was part of one designed to evaluate nitrogen (N) and phosphorus (P) fertilization as well as seedbed density. The design and installation of the experiment were described in a previous paper (Brissette and Carlson 1987), and will be only briefly reviewed here. There were two levels of P, five levels of density, and four levels of N applied in a split-split plot design with four replications. The levels of P were the level in the soil before the experiment and enough 0-300-0 fertilizer incorporated prior to seedbed formation to theoretically raise the level 150 percent. No significant effects were attributed to the P treatments (Brissette and Carlson 1987).

Ammonium sulphate was applied in five biweekly topdressings at levels ranging between 55kg N/ha and 170kg N/ha. The effect of N on morphological attributes peaked at an intermediate level, and interacted with mean seedbed density in its effect on root growth potential (Brissette and Carlson 1987).

The study was sown on April 16, 1985, with Weyerhaeuser-designed precision vacuum equipment that sowed eight double rows of seeds. The five target densities of living seedlings were: (1) 160/m², (2) 230/m², (3) 295/m², (4) 360/m², and (5) 430/m².

Actual average seedbed densities were lower than the target densities because germination was poorer than expected. Average density for each level in the study was: 141/m², 218/m², 269/m², 296/m², and 296/m². Note that the two highest levels were the same. Although the highest density was well below the sowing target, it was higher than the operational level (270/m²) recommended by Chapman (1948) but much lower than the density (540-590/m²) suggested as a maximum by Wakeley (1954).

Early in the study a transect was taken across the center of each plot and one seedling from each double drill row was permanently tagged as a measurement tree. Thus, 1280 identified seedlings were followed throughout the study. Those seedlings are the basis for this paper.

To determine effective density we reasoned that seedling shoots are most affected by other seedlings that are closer than about 15 cm. Root competition probably occurs at greater distances,

but we assumed that most water and nutrient uptake is also within 15 cm. Thus, seedlings sown in conventional drills on 15 cm spacing compete within their own drill row and with seedlings in adjacent drill rows. To determine the effective density of each of the labeled seedlings the number of seedlings in the double drill row for 15 cm on either side was added to the similar number obtained on adjacent drill rows. The total is an estimate of the number of seedlings with which the measurement tree was competing.

Because competition is usually expressed as the number of seedlings per unit area, the number of competing seedlings was converted to number per square meter, i.e., the effective density for each measurement tree. The conversion was based on the area included in obtaining the number of competing seedlings. The measurement area was 30 cm long, the nursery beds were 1.2 m wide with eight drill rows. Since the seedlings from the six interior drill rows are competing with those on either side (three rows total) the area was calculated to be $3/8 \times 1.2 \text{ m} \times 0.3 \text{ m} = 0.135 \text{ m}^2$. The effective density was then calculated as the number of competing seedlings/0.135 m²--for example, 36 seedlings/0.135 m² = 267 seedlings/m². Because the seedlings on the outside of the nursery bed only have one adjacent drill row (two competing rows) their area of competition was calculated to be $1/4 \times 1.2 \text{ m} \times 0.3 \text{ m} = 0.09 \text{ m}^2$. Thus for a seedling on the outside drill row competing with 19 additional seedlings, its effective density is 20 seedlings/0.09 m² = 222 seedlings/m².

Each of the 1280 measurement seedlings was labeled with an aluminum tag attached to the stem with a wire. When the beds were laterally root pruned prior to lifting the tags and wires caused extensive stem damage. When the seedlings were hand-lifted on January 20-21, 1986, 970 of the original 1280, were undamaged. These undamaged were measured for root collar diameter, height (shoot length), and root volume, using the displacement method (Burdett 1979). The seedlings were kept in cold storage between lifting and planting except when they were being measured. The measurements were made in a laboratory and required less than 5 min per seedling.

On February 7, 1986, the seedlings were machine-planted on a sod-covered site at the J. K. Johnson Tract of the Palustris Experimental Forest west of Alexandria, LA. On March 5-6, 1987, the total height and ground line diameter of all living trees were measured. Relative growth rates (RGR) were calculated as percent change in height and diameter between the nursery and first-year field measurements (field measurement-nursery measurement/nursery measurement \times 100).

Seedling morphology and first-year field performance data were analysed by regression techniques. The 970 trees were subdivided in 10 density classes of 97 observations each and the means were used in the analyses.

RESULTS AND DISCUSSION

The effective densities for the 970 seedlings ranged from 55 to 431 seedlings/m² with a mean of 246/m² and a coefficient of variation (CV) of 30 percent. When divided into 10 subclasses of 97 seedlings each, the mean densities ranged from 123 to 365/m² (table 1). The amount of N available per seedling was computed by dividing the total N applied by the effective density. It ranged from 13 to 260 mg/seedling with a mean of 47 mg/seedling. Within the density classes, mean N ranged from 30 to 87 mg/seedling (table 1).

With density as the independent variable, regressions with the three morphological characteristics as dependent variables were all significant ($p < .001$). Coefficients of determination (r^2) were 0.78, 0.92, and 0.98 for height, diameter, and root volume respectively. field performance. Under operational conditions where the rate of N application is usually more uniform than bed density, this relationship may be even more important.

Nursery bed density clearly had affected seedling morphology at time of lifting (table 1).

Table 1.--Nursery bed density effects on shortleaf pine seedling morphology and first-year field performance

Density class	Mean density	Mean N ^{a/}	Nursery			First-year field		Relative growth	
			Ht	Dia	RV ^{b/}	Ht	Dia	Ht	Dia
	--/m ² --	-mg/tree-	--mm--	--cc--		-----mm-----		-----%-----	
1	123	87	163	4.8	4.1	357	6.8	124	42
2	155	65	167	4.7	3.9	373	6.8	130	47
3	188	59	181	4.7	3.5	356	6.5	100	41
4	217	46	182	4.6	3.3	353	6.2	100	36
5	237	43	183	4.6	3.2	356	6.1	100	36
6	261	39	181	4.4	2.8	348	5.9	94	38
7	282	38	182	4.4	2.7	328	5.8	86	37
8	303	33	183	4.3	2.7	328	5.8	82	38
9	331	32	187	4.3	2.6	335	5.7	83	35
10	365	30	190	4.3	2.5	328	5.6	76	32
r^2 ^{c/}		.98	.78	.92	.98	.75	.97	.88	.68

^{a/} N = nitrogen

^{b/} RV = root volume

^{c/} r^2 = coefficient of determination with mean effective density as the independent variable, see text for individual regression equations

Determination of nutrient uptake in fertilizer experiments requires destructive sampling. For this study concentrations of N, P, and K in seedling shoots were reported previously (Brisette and Carlson 1987). Although a theoretical amount of N was calculated for each seedling on the basis of effective density, it cannot be confirmed. Therefore, this paper's discussion is confined to the effects of density. Differences due to the four N rates applied are taken into account by analyzing the means of the density classes that are made up of approximately equal numbers from each N treatment. As shown in table 1, the average amount of N available per seedling decreases as density increases. Thus the effects of density on an individual seedling cannot be totally separated from the effects of N. This relationship should be kept in mind during the following discussion about morphology and field performance. Under operational conditions where the rate of N application is usually more uniform than bed density, this relationship may be even more important.

As mean density increased, mean height increased while mean diameter and root volume decreased. With density as the independent variable, regressions with the three morphological characteristics as dependent variables were all significant ($p < .001$). Coefficients of determination (r^2) were 0.78, 0.92, and 0.98 for height, diameter, and root volume respectively.

Nursery managers seldom have a seedlot or even a species growing at the range of densities represented in this study. For pines, managers are most interested in densities between 215 and 325/m². To evaluate this range in more detail, we selected two of our density classes and compared them with analysis of variance (ANOVA). The classes selected from table 1 were 4 and 8. Class 4 had a mean density of 217/m². It had a relatively narrow range of densities of from 204 to 226/m². Class 4 is the one just above the biological optimum density recommended for loblolly pine by Mexal (1981). At most nurseries

it would be considered low density. Class 8 had a mean density of 303/m² and a range (between 292 and 316/m²) nearly as narrow as Class 4. Class 8 would be considered moderately high density.

Seedlings from Classes 4 and 8 did not differ significantly in height (MSE=1521, $p = .905$). Although the difference in mean diameters was only 0.3 mm, it was significant (MSE=0.96, $p = .020$). The 0.6 cc difference in root volume was also significant (MSE=1.33, $p < .001$).

Nursery managers often evaluate their crop quality as the percentage of seedlings that exceeds some minimum standard. For the southern pines, morphological seedling grades were developed by Wakeley (1954), drawing on several years of research results and operational observations. These grades are still recognized as the standard measure of southern pine seedling quality. Three grades are defined, two plantable and one cull, based primarily on root collar diameters of undamaged seedlings. For shortleaf pine the minimum diameter for plantable seedlings (Grade 2) is 3.2 mm while the minimum for premium seedlings (Grade 1) is 4.8 mm. In our density Class 4, only 3 percent of the seedlings were less than 3.2 mm and would have been considered culls, while in Class 8, 12 percent were culls. In Class 4, 40 percent of the seedlings were Grade 1, while in Class 8, 30 percent were Grade 1.

Root volume is seldom evaluated operationally but is considered one of the most important morphological characteristics. During the period between planting and elongation of new roots, root volume largely determines the level of plant moisture stress that can develop (Carlson 1986). Larger root volumes also provide more sites for new root growth, thus root volume has been positively related to root growth potential in both loblolly pine (Carlson 1986) and shortleaf pine (Brissette and Carlson 1987). For these reasons large root volumes are especially important when seedlings are planted on droughty sites. However, root volume is extremely sensitive to nursery bed density. Across our 10 density classes, root volume decreased sharply as density increased (fig. 1).

First-year field survival was excellent, being 98 percent overall. Among seedbed density classes, first-year survival was between 96 and 99 percent. Field growth was statistically related to nursery bed density (table 1). The regression between first-year field height and seedbed density was significant ($p < .005$, $r^2 = 0.75$). But, unlike nursery height, field height decreased as the density at which the seedlings were grown increased (fig. 2). That is, the shortest trees from the nursery were the tallest in the field after the first growing season. First-year field diameter was also significantly related to nursery density ($p < .001$, $r^2 = 0.97$). Like nursery diameter field diameter decreased with increasing seedbed density (fig. 3).

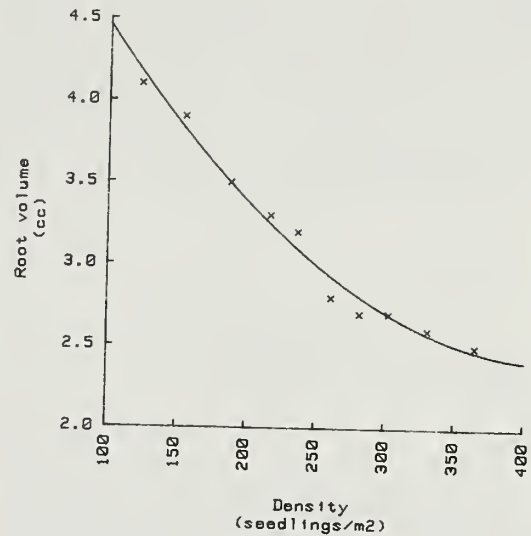


Figure 1.--Relationship between mean effective density and mean root volume of shortleaf pine seedlings, $n=97$.

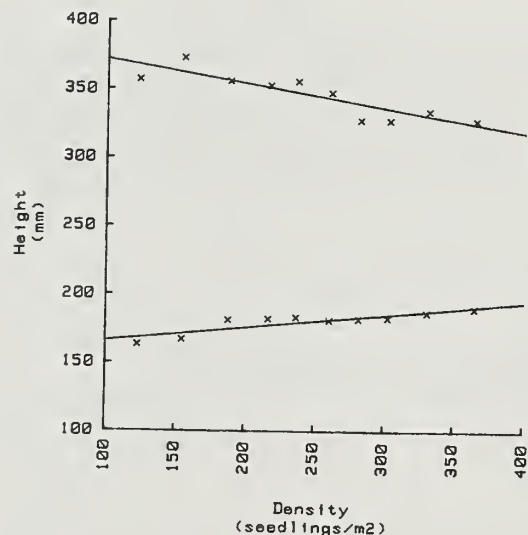


Figure 2.--Relationship between mean effective density and mean shortleaf pine seedling height at lifting (lower curve, $n=97$) and after one year in the field (upper curve, $n=93-96$).

In terms of RGR, changes in heights and diameters between the nursery and the field were also related to nursery density (table 1). For

the 970 trees, the mean RGR for height in the field was 97 percent; 100 percent represents a doubling in size. When regressed with seedbed density the relationship was significant ($p < .001$, $r^2 = 0.88$). Diameter RGR was not nearly as great with an overall mean of 38 percent, but was also significantly related to nursery density ($p < .005$, $r^2 = 0.68$). For both height and diameter, RGR in the field declined with increasing nursery density (fig. 4).

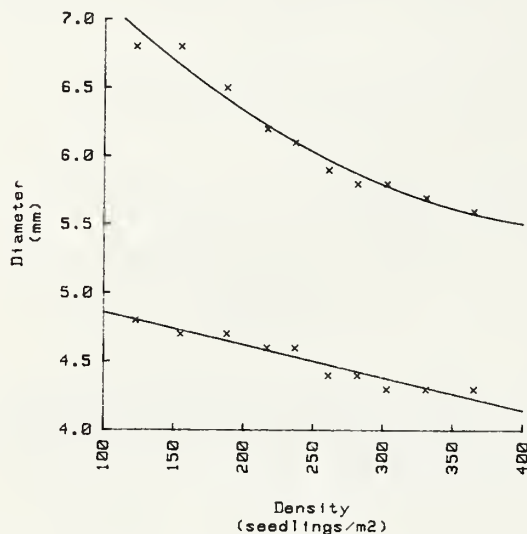


Figure 3.--Relationship between mean effective density and mean shortleaf pine seedling root collar diameter at lifting (lower curve, $n=97$ and ground line diameter after one growing season (upper curve, $n=93-96$).

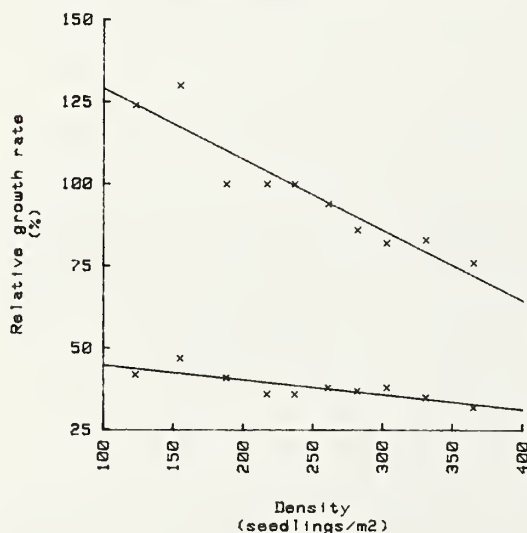


Figure 4.--Relationship between mean effective density and mean relative first-year growth rates (field measurement-nursery measurement/nursery measurement $\times 100$) for seedling height (upper curve, $n=93-96$) and diameter (lower curve, $n=93-96$).

Both nursery managers and foresters benefit when they agree on a set of specifications for a target seedling that will give the desired performance on a particular planting site. Target seedling specifications differ somewhat from seedling grades because targets are based on performance goals. Thus target specifications are often more stringent than morphological grades, which are usually based on a minimum performance level. One proposed goal for southern pines is a doubling in height during the first growing season in the field (Brisette 1985). Data from this study can be used to help specify a target seedling that will meet that goal. The regression equation for relative height growth in terms of nursery density (X = seedlings/ m^2) is:

$$RGR\ HT = 150.5 - 0.21537X, r^2 = 0.88$$

To achieve a doubling in height (100 percent change), the equation predicts a density of 235/ m^2 . The equations for nursery height (HT), diameter (DIA), and root volume (RV), in relation to density are:

$$HT = 156.2 + 0.09608X, r^2 = 0.78$$

$$DIA = 5.1 - 0.00237X, r^2 = 0.92$$

$$RV = 5.9 - 0.01648X + 0.00002X^2, r^2 = 0.98$$

These equations predict that a seedling capable of doubling in height under the conditions of this study: (a) is no more than 179 mm tall (minimum mean height in the data set was 163 mm), (b) is at least 4.5 mm in root collar diameter, and (c) has a root volume of at least 3.1 cc. These specifications could also be estimated graphically from figures 1-4.

These specifications are based on seedlings grown on a less droughty site than those typically found in the mountains. However, the height suggested by the analysis is at the low end and the diameter is at the high end of the range of specifications given for an initial target seedling to be planted on Ouachita and Ozark Mountain sites (Barnett and others 1987). Therefore, we think that the root volume suggested by this analysis is an appropriate addition to those target specifications. Note that 3.1 cc is the target root volume, the minimum acceptable would be somewhat less and would depend on what was defined as a minimum performance level.

SUMMARY AND RECOMMENDATIONS

This study was designed to evaluate the effect of nursery bed density on the morphology and subsequent field performance of shortleaf pine seedlings. Because seedling morphology is so strongly related to seedbed density, it was not possible to separate the effects of density and morphology on field performance in this study. However, based on the above results and discussion the following recommendations are made:

1) To produce shortleaf pine seedlings with the morphological characteristics for rapid first-year growth in the field, nursery bed density should be kept below 235/m².

2) For any species, root volume should be included in the development of target seedling specifications. While not as easy to measure as shoot length or diameter, root volume determination is not excessively difficult nor time consuming.

3) Because density can influence seedling nutrient status, it should be remembered that the effects of density on growth and performance are confounded by the effects of fertilization.

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Polymeric Nursery Bed Stabilization to Reduce Seed Losses in Forest Nurseries¹

William C. Carlson, John G. Anthony, and R. P. Plyler²

Abstract: A polymerization treatment using Geotech, a copolymer of acrylate and vinyl acetate monomers, was used to stabilize forest nursery beds to substantially reduce wind and water erosion. Such treatment did not affect either the temperature of the seed zone in the soil or germinant emergence. Seed losses were reduced by the treatment, resulting in increased nursery yield.

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Improving Outplanting Survival of Stored Southern Pine Seedlings by Addition of Benomyl to the Packing Medium¹

James P. Barnett and John C. Brissette²

Abstract.-- Field survival of longleaf, shortleaf, slash, and loblolly pine seedlings planted with benomyl incorporated in the packing medium was markedly improved over that of controls with clay-slurry packing medium. Longleaf pine (*Pinus palustris* Mill.) and shortleaf pine (*P. elliottii* Englem.) seedlings, which are more difficult to store, had greater magnitudes of response than the more easily stored loblolly and slash pine seedlings.

INTRODUCTION

Clay-benomyl (Benlate®)³ mixture used as a root dip treatment at the time of planting provides systemic protection of longleaf pine (*Pinus palustris* Mill.) seedlings from brown-spot disease (*Scirrhia acicola* (Dearn.) Siggers). Protection should last for at least one year in the field (Kais and Barnett 1984; Cordell et al. 1984; Kais et al. 1986a, 1986b). This treatment has resulted in improved survival and early height growth (Kais 1985; Kais and Barnett 1984; Kais et al. 1986b). Benomyl is a very effective fungicide that is recommended for a number of other uses in container and bare-root nursery seedling production (Barnett and Brissette 1986; Sutherland 1984). It also has the advantage of having no phytotoxic effect on mycorrhizal development; in fact, seedling development is enhanced by benomyl use (Pawuk and Barnett 1981).

Recent tests have shown that longleaf pine seedling storage may be dramatically improved by the incorporation of benomyl into the clay slurry used for seedling packing (Barnett and Kais 1987). Early results have stimulated additional testing and extension of the technique to other species.

METHODS

Three studies are underway by the Southern Forest Experiment Station to evaluate the effect of fungicides on storage of southern pine seedlings. In study 1, longleaf pine seedlings from a single seed lot were lifted in January 1985 from beds at the Ashe Nursery in Mississippi. Seedlings were divided into two sublots for two storage periods (1 and 3 weeks), and five root packing material treatments were applied for each storage period: (1) clay slurry control, (2) clay slurry, with a benomyl dip added at the time of planting, (3) clay slurry with benomyl added at the time of packing, (4) peat moss control, and (5) peat moss combined with a benomyl dip treatment. Benomyl was applied as a 10-percent mixture of Benlate® WP50 with kaolinate clay. This resulted in an approximate 5-percent a.i. of benomyl in the clay slurry or dip. A 10-percent dilution of benomyl in water was used as a dip prior to packing with peat moss for treatment 5.

In study 2, longleaf pine, loblolly pine (*P. taeda* L.), and shortleaf pine (*P. echinata* Mill.) seedlings from the Ashe Nursery were lifted in January 1986 and divided into three sublots for three storage periods (0, 3, and 6 weeks). Two root packing treatments were applied to each of the three sublots: (1) clay slurry control and (2) 10-percent Benlate® WP50 and clay slurry mixture.

In study 3, two seedlots (Florida and Mississippi) of slash pine (*P. elliotti* Engelm.) and three (Alabama, Louisiana, and north Mississippi) of loblolly pine were lifted at the Ashe Nursery late in the season (March 9, 1987) and subdivided for two treatments (0 and 6 weeks). The dosage rate was reduced to one-fourth the rate of the earlier test, i.e., a 2.5-percent mixture of Benlate® WP50 and kaolinate clay. The control was a clay slurry.

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³Mention of trade names is for information only and does not constitute endorsement by the USDA Forest Service.

In all tests, seedlings were packed in Kraft polyethylene bags (350 per bag) and stored at 35°F. Seedlings of the 0 week treatment were planted within 3 or 4 days, while the other plantings were made after 3 or 6 weeks of storage. Seedlings were machine planted at 5- by 5-foot spacings in 2 rows of 50 seedlings; there were 4 replications. Study 1 was outplanted on two different sites in central Louisiana. Only one site was used for the other two studies. Seedling survival was measured in June and December of the same year following planting. Study 1 was also measured for survival and height after 2 years in the field.

Differences in survival were tested for significance at the 0.05 level by analyses of variance. Duncan's Multiple Range Test was used to evaluate treatment means.

RESULTS

Study 1.--The outplanting site had a considerable influence on longleaf pine seedling survival after two growing seasons. Heavier grass and woody competition as well as greater brown-spot incidence occurred on site 1. Nevertheless, treatment effects followed the same trends on both sites. Both length of seedling storage and packing-medium treatments significantly affected seedling performance. Survival of seedlings that had undergone 3 weeks of storage was markedly lower than for the 1-week storage period (fig. 1). The effect of storage varied greatly depending on packing-medium treatments, and for both sites there was a storage X packing treatment interaction.

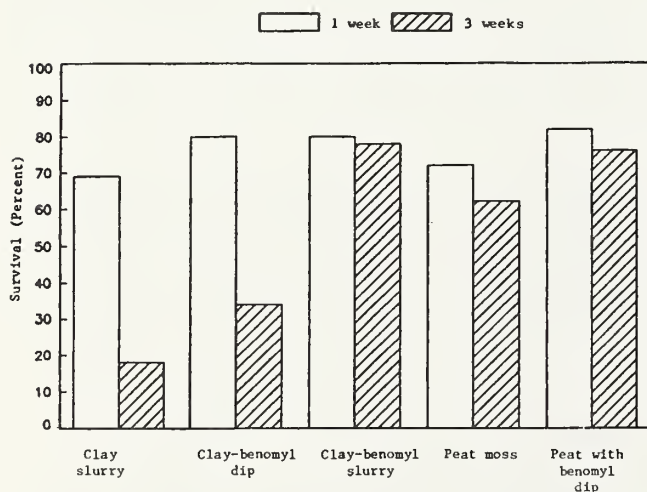


Figure 1.--Survival of longleaf pine seedlings stored 1 and 3 weeks with various root packings 2 years after outplanting (Study 1.)

The clay-slurry and peat moss controls had consistently lower survival than any of the benomyl treatments when stored 1 week (fig. 1). The magnitude of treatment difference was much greater

for the 3-week storage treatment. The clay-slurry treatments averaged 19, 33, and 79 percent survival for the control, benomyl dip at planting, and the clay-benomyl slurry, respectively. The peat moss control averaged 64 percent, three times that of the clay-slurry control. The addition of benomyl to the peat moss treatment improved survival by 13 percentage points.

Study 2.--Longleaf, loblolly, and shortleaf pine seedlings receiving clay-slurry control and clay-benomyl treatments were planted after storage periods of 0, 3, and 6 weeks. Response after 1 year varied by species. Longleaf pine seedlings had the lowest survival regardless of treatment, and benomyl improved survival after all lengths of storage (fig. 2). In contrast, survival of loblolly pine seedlings was almost 100 percent regardless of treatment or storage. Survival of shortleaf pine seedlings without storage (0-week storage period) averaged 99 percent, but after being stored for 3 and 6 weeks, survival of the controls dropped to 83 and 36 percent, respectively. Benomyl-treated shortleaf seedlings maintained the same level of survival even after storage (fig. 2).

Study 3.--The loblolly and slash pine seedlings lifted later in the season (March 9) were planted within 1 week (0-week storage period) and after 6 weeks. These seedlings were treated with the clay slurry and a clay-benomyl slurry at one-fourth the rate used in the slurries of the other studies. After 3 months in the field, there were marked differences between packing treatments. Loblolly pines stored 6 weeks averaged 23 and 87 percent, respectively, for the clay and clay-benomyl treatments (fig. 3). Comparative treatments for slash pine averaged 9- and 88-percent survival.

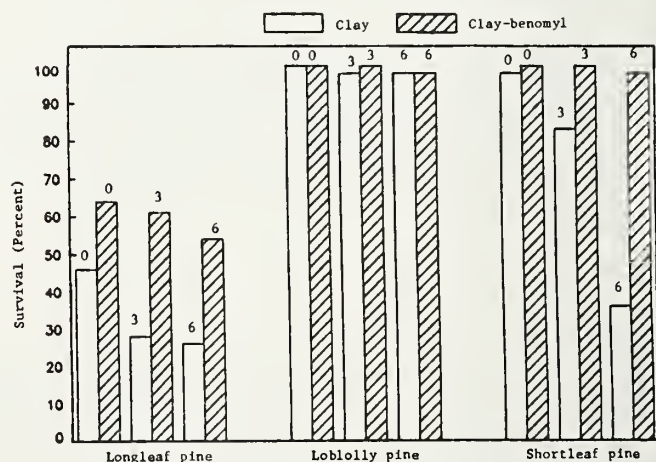


Figure 2.--Survival of longleaf, loblolly, and shortleaf pine seedlings stored for 0, 3, and 6 weeks with two root packings 1 year after outplanting (Study 2). Numerals above bars represent number of weeks stored.

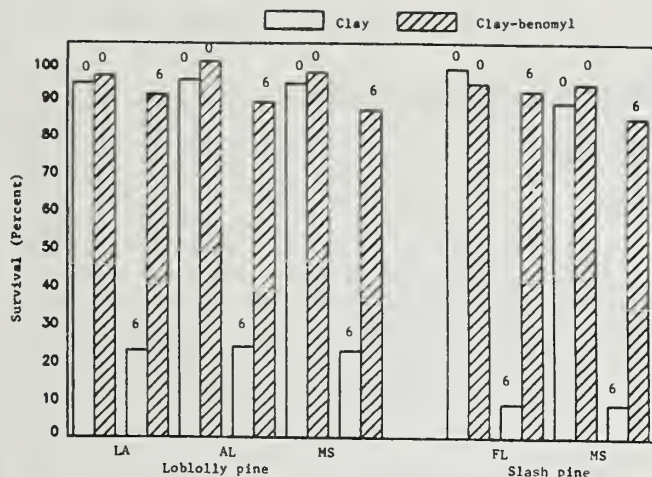


Figure 3.--Survival of loblolly and slash pine seedlings stored for 0 and 6 weeks with two root packings 3 months after outplanting (Study 3). Numerals above bars represent number of weeks stored.

DISCUSSION

Results of all three tests showed a very positive response from the incorporation of benomyl into the clay slurry used for seedling packing. The root dip in benomyl followed by seedling storage in peat moss followed the same trend. Preliminary pathological evaluations indicate that benomyl is controlling pathogenic microorganisms that reduce seedling quality after storage of 3 or 6 weeks. Survival of longleaf pine seedlings, which are the most difficult of the southern pines to store, is improved by benomyl treatment even when the seedlings are outplanted within 1 week. The second greatest response was with shortleaf pine. Major improvements in shortleaf pine survival occurred with 3 to 6 weeks of storage.

Loblolly pine seedlings lifted in early January survived well without benomyl treatment. However, when loblolly and slash seedlings were lifted in March and stored for 6 weeks, seedlings that received benomyl treatment were able to be stored satisfactorily. Those without such treatment showed a large decrease in survival. Additional studies are underway to evaluate the mechanisms involved in deterioration of seedlings during storage; other studies are underway to determine the effect of date of lifting on seedling storage.

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Measuring Tree Seed Moisture Content Now and in the Future

Robert P. Karrfalt¹

Abstract.-- The procedure used in developing conversion charts for tree seed for use with a relatively inexpensive electronic seed moisture tester is given. A list of the species for which charts have been made is given. A brief discussion is presented on the potential future uses of regulating seed moisture.

INTRODUCTION

The regulation of seed moisture is critical to the management of high quality seed. Mechanical injury or high temperatures can have detrimental effects to be sure, but the moisture content of seeds no doubt is the most influential of all the factors that can effect the quality of seeds (Justice and Bass, 1979). The date of harvest of cones, fruits, or seeds is generally related to moisture content. Conifer cones must be air dried to a specified range of moisture content in order to produce maximum yields and highest quality seed. Kiln drying of cones that are too high in moisture content will result in case hardening of the cone and a poor seed yield. Most temperate zone species that have moisture contents below 10 percent can be stored at cold temperature for years while seed at high moisture content will live only a few months even with ideal temperatures. These are but a few brief examples of how critical the regulation of seed moisture is to the quality of seed.

ROUTINE SEED STORAGE

For routine seed storage the seed handler is concerned with maintaining seed basically at a threshold moisture level. For the vast majority of temperate species this threshold value is 10% on a wet weight basis. Extremely low values of 2 or 3% might lead to seed damage according to some reports, but data (Justice and Bass, 1979, Benson, 1970) exists that shows that this is probably not the case. The examples of loss of viability due to low moisture content are probably explainable as imbibitional injury when planted. A slow uptake of water would allow those seeds with ultra low moisture contents to maintain a high level of viability.

A desirable test for moisture is one that is fast, inexpensive, and gives acceptable accuracy. There are a number of electronic moisture testers available that will give quick results. However, they generally cost about \$1,000 or more. For the small forestry operation this might represent a substantial portion of the annual budget for equipment. So for many the \$1000 meter may not be inexpensive. Also none of the meter manufacturers concern themselves with forestry and conservation seeds in the calibration of their meters. Therefore, the meter will not be useable until someone conducts the necessary measurements to relate meter readings to actual seed moisture contents.

For many years a small meter was available for which the National Tree Seed Laboratory had developed conversion charts. This was the PB-71 made by the Eaton Corporation. It was marketed under a number of names: Dole, Radson, Burrows, and Gilmore-Tatge. Unfortunately this meter was improved for the tester of grains, and tree and shrub seed testers could no longer use it. The electronic parts were modified such that they no longer functioned in the range needed for woody plant seed. To quickly replace this much needed meter, an effort was made in cooperation between the National Tree Seed Laboratory and many private and public agencies to develop conversion charts for another, relatively inexpensive meter, the Dickey-john¹ grain moisture tester for corn. The following have donated seed for this work: R. W. McPhearson, California Division of Forestry, Michigan Department of Natural Resources, Dean Swift Seed Company, Louisiana Forest Seed Company, W.W. Ashe Nursery, J. Herbert Stone Nursery, J.W. Toumey Nursery. The effort to develop charts is still going on, and the NTSL will be happy to develop a chart as soon as possible if your desired species are not on the charts.

¹Director, National Tree Seed Laboratory,
USDA Forest Service, Dry Branch, Georgia.

¹Use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

DEVELOPMENT OF THE CONVERSION CHARTS

The procedure followed in developing the moisture charts for the Dickey-john meter was based on the following reasoning. 1. The variation in meter readings among samples from the same seed lot and among seed lots at any given moisture content would be small (less than one percent moisture). If variation was large then the meter would not be useful because multiple readings would be required, and the meter would not be a quick test. 2. It follows from the first statement that the samples tested in the meter could all come from one seed lot if that seed lot was at all representative. 3. The concern in storing tree seed is that the moisture content be below a given threshold value. Therefore, whether the true moisture is 5, 6 or 8% is not important. What is important is that we are certain that the value is below the critical threshold. Our primary concern in developing these charts was, therefore, not necessarily to have a high degree of precision but to have numbers that will tell us that we have our seed dry enough for long term storage.

The first step in developing the charts was the selection of a seed lot that was of good average germination and purity for the species. This seed lot was then soaked overnight in water to fully imbibe the seed. The water was drained off, and the seed was placed on the seed drier. As soon as the seed was surface dry, a reading was taken on the meter and in the drying oven. The drying oven moisture determination was done on duplicate 5 gram samples at $103^{\circ}\text{C} \pm 2^{\circ}\text{C}$ for 17 hours ± 1 hour (International Seed Testing Association, 1985). Generally the moisture content was in the neighborhood of 20 to 25% on the first reading. Subsequent readings were taken every one to two hours depending on how fast the drying was taking place. Readings were taken until the seed reached moisture contents of 4 to 6%. In some cases the end moisture content achieved was only 7 or 8%. Some of the species tested had a conversion chart developed for the PB-71 meter. Readings from the PB-71 served as a check that the seed lot being used was representative of the species. The reasoning on that point was this. If the reading from the PB-71 was within tolerance with the oven reading, then there was confidence that the seed lot being used was representative. In all cases the readings were within tolerance so that the procedure of using one seed lot seems valid.

The second step was the regression of the meter readings on the moisture contents determined by the oven procedure. This regression produced a prediction equation for calculating the meter readings from oven measurements. Using oven measurement values from 6 to 18% in steps of 0.5% a set of meter readings was computed from the prediction equation. The computed values are the

conversion chart values. The measurements made with the Dickey-john meter on several loblolly pine seed lots agree with the readings found by the oven, and show that the procedure is appropriate.

Conversion charts have been made for the following species:

WESTERN SPECIES

Abies concolor
Abies grandis
Abies magnifica
Calocedrus decurrens
Picea engelmannii
Picea sitchensis
Pinus contorta
Pinus coulteri
Pinus jefferyi
Pinus lambertiana
Pinus muricata
Pinus ponderosa
Pinus radiata
Pseudotsuga menziesii

NORTHERN SPECIES

Betula papyrifera
Betula allegheniensis
Larix laricina
Picea abies
Picea glauca
Picea mariana
Pinus banksiana
Pinus resinosa
Pinus strobus
Thuja plicata
Tsuga canadensis
Crataegus phaenopyrum

SOUTHERN SPECIES

Pinus clausa
Pinus elliottii
Pinus palustris
Pinus taeda
Pinus virginiana

Persons needing the charts may obtain them from the National Tree Seed Laboratory, Rt. 1, Box 182B, Dry Branch, GA 31020.

REGULATION OF SEED MOISTURE CONTENT IN THE FUTURE

To this point we have talked about regulating seed moisture as a very basic technology. We wanted only to maintain our seed below a given threshold of moisture so that we could safely have long term storage of seed. This is an extremely important aspect of seed moisture that will stay with us for as long as we store seed in the manner we currently do.

During the last 10 years, however, the literature has had some articles on regulating moisture content of stratified seed that allows the nursery manager to store seed while either maintaining the benefits of stratification or even enhancing the benefits of stratification. Danielson and Tanaka (1978) found that by air drying stratified seed of Douglas fir and ponderosa pine that the seed could be stored for up to 9 months without reinstating dormancy or causing deterioration of the seed. Belcher (1982) confirmed the findings of Danielson and Tanaka with Douglas fir and found the same to be true for loblolly pine. De Matos Malavasi et. al. (1985) showed that seedlings produced from air dried Douglas fir seed were larger at age 5 days than seedlings from seed which were stratified only. Numerous studies on improving the vigor of seeds by priming with PEG have been reported in the literature. It seems quite likely that the improvement in vigor might come from an effect brought on by the PEG regulating the moisture content of the seed. It is also well established that the moisture content of the seed and its various constituent parts has a profound control over the condition of the cell membranes and the metabolic and chemical activities that occur within the seed (Priestly, 1986).

In the future it is very likely that seed handlers will want to regulate the seed moisture for purposes of regulating the effects of the presowing treatments. Today's forms of stratification could well be replaced with more sophisticated procedures. To do this we will want to measure moisture in ranges between 20% and 30% or 40%. A type of meter like the Dickey-john will allow for quick measurements in this range. . Therefore, as the seed physiologists discover the critical moisture contents to regulate seed

performance, the technology exists to adapt this new information for practical application by the nursery manager.

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Forest Tree Nursery Herbicide Studies at the Oklahoma Forest Regeneration Center¹

Lawrence P. Abrahamson²

Abstract.—Eight herbicides (registered for similar uses in the U.S.) were extensively evaluated at the Forest Regeneration Center, Oklahoma Forestry Division, Washington, Oklahoma, for weed control on first year seedling nursery beds. Phytotoxicity evaluations of dcpa, napropamide, oxyfluorfen, diphenamid, bifenox, oxadiazon, trifluralin and prometryn on 19 different conifer and hardwood species are presented.

Additional key words: Enide®, Treflan®, Dacthal®, Caparol®, Devrinol®, Modown®, Goal®, and Ronstar®.

INTRODUCTION

The USDA Forest Service developed a number of nursery herbicide projects in the United States out of a recognition of the potential benefits of herbicidal control of weeds in nursery seedbeds. This paper will concentrate on projects conducted at the Forest Regeneration Center, Oklahoma Forestry Division, Washington, Oklahoma. The Oklahoma tree nursery was part of the following projects. The cooperative western nursery herbicide project, initiated in 1976, with cooperation among state, private and federal nurseries, Forest Service Research, State and Private Forestry, National Forest Systems, and State University of New York out of Syracuse. Twenty-eight nurseries in 12 states were involved in this effort which was broken down into three segments, each of three-year duration: the Pacific Coast started in 1976 (Stewart 1977, Owston et al. 1980, Owston and Abrahamson 1984), the Intermountain-Great Basin in 1977 (Ryker and Abrahamson 1980), and the Great Plains in 1978 (Abrahamson 1981, Abrahamson and Burns 1979) which the Oklahoma Nursery was a part of. In 1979 the Northeastern (NE) Area started an eastern nursery herbicide project in five states cooperating with Purdue University and State University of New York (SUNY) at Syracuse (Holt and Abrahamson 1980). In 1981 the NE Area expanded the eastern nursery herbicide project to the Great Lakes area with eight nurseries (state, federal and private) in

three Lake States cooperating with SUNY (Abrahamson and Jares 1984).

During 1982, after the Great Plains segment of the cooperative western nursery herbicide project was completed, Oklahoma State (Abrahamson 1983) sponsored a nursery herbicide project of their own in cooperation with SUNY to help the nursery expand on the herbicide studies using different herbicides, tree species and sowing times. This study has continued on a yearly basis through 1987-88.

What is important in these projects is that all studies have similar objectives and methodologies and that information developed from one region or study project is supportive of that from other regions. In all these studies the objectives were to identify promising herbicides, develop data for product registration, and demonstrate safe and effective weed control practices for nursery seed beds.

METHODS

The nursery herbicide screening and demonstration projects were initiated as part of a three-year study. During the first year of the three-year study up to ten herbicides (eight of which are represented in Table 1) were screened on two to four major species of spring- and/or fall-sown conifers and/or hardwoods depending on the year involved in the study.

Treatments were applied to three- or six-foot long plots in four-foot wide nursery beds with a one-foot untreated buffer between plots. All treatments were installed in a randomized block design with three replications per species. Herbicides were applied with a modified Hudson®

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Table 1. Herbicides, rates, and application timings used in the Nursery Herbicide Studies Conducted by SUNY at the Oklahoma Forest Regeneration Center.

Herbicide	Formulation	Manufacturer	(lb ai/A)	Application Timing		
				Inc ¹	or Ps ²	Pg ³ Ps + Pg ⁴
Diphenamid	Enide 50W; 90 W	Nor-Am	4.0	x	x	x
Trifluralin	Treflan 4EC	Elanco	0.75	x	-	-
DCPA	Dacthal W-75	SBS Biotech	10.5	x	x	x
Prometryn	Caparol 80W	Ciba-Geigy	1.0	x	x	x
Napropamide	Devrinol 50W	Stauffer	1.5/3.0	x	x	x
Bifenox	Mowdown 80W; 4F	Rhone-Poulenc	3.0	x	x	x
Oxyfluorfen	Goal 2E; 1.6E	Rhom & Haas	0.5	x	x	x
Oxadiazon	Ronstar G	Rhone-Poulenc	1.0	x	x	x
Napropamide & Bifenox	Tank Mix		1.0+3.0	x	x	x

¹Pre-seeding incorporation: incorporated into top 2 inches of soil immediately before seeding.

²Post-seeding: broadcast applied to soil immediately after seeding.

³Post-germination: broadcast applied to soil 4 to 5 weeks after seedling emergence.

⁴Post-seeding plus post-germination: two separate applications at the full recommended rate.

type pressure hand sprayer, or a modified AZ plot pressurized sprayer equipped with check valves and four flat fan 8001 nozzles operated at 20 psi in a water carrier at a volume equivalent to 85 ppa (100 ml/three-foot plot). Granular formulations were ocularly applied from a hand shaker uniformly over the plot.

Pre-seeding incorporated treatments were applied no more than one day before seeding and incorporated into the top two inches of soil using a garden rake. Post-seeding treatments (Ps) were applied within two days after seeding, except on the fall-sown species which were applied any time after fall seeding but before mulching. Post-germination treatments (Pg) were applied four to six weeks after seedling emergence, except on the fall-sown species which were applied in the spring after seedlings had emerged.

Herbicidal damage to conifers/ hardwoods at the end of the first growing season was evaluated using a ten-point rating scale (0 is complete kill, 10 is no effect) proposed by Anderson (1963). Height of nine randomly selected seedlings and number of seedlings per foot in three randomly selected rows in each plot were also measured to determine chemical effects on germination, seedling growth and survival.

The objectives of the second-year studies were to evaluate the phytotoxicity and weed control effectiveness of three to four herbicides screened from the first-year study to be non-phytotoxic to the species tested and have reasonable weed control of weeds present at that nursery. Phytotoxicity was evaluated by using herbicidal damage ratings (Anderson 1963), seedling survival (number/foot) and height growth (cm). Dosages of 1X, 2X, and 1X

+ 1X of these herbicides were applied post-seeding and/or post-germination using three- or six-foot long plots in four-foot wide beds with a one-foot untreated buffer between plots. All treatments were installed using a randomized block design with three replications per species. Herbicide treatments were applied by small pressurized sprayer or hand shaker as was done the first year of these studies.

During the Great Plains part of the Oklahoma studies, weed control effectiveness of the best treatments were evaluated under operational use using nursery application equipment on 100-foot test plots. The herbicides were evaluated for weed control under operational use at the 1X rate of application applied post-seeding along, or post-seeding and post-germination. Phytotoxicity rating, survival and height measurements were also recorded from these operational plots.

RESULTS AND DISCUSSION

Earlier results from the Oklahoma nursery studies has been reported in a similar manner (Abrahamson 1984, 1986). Phytotoxicity data from all Oklahoma studies through 1987 is presented in Tables 2-12, listed by herbicides tested under each species. The tables are summaries of all the phytotoxicity studies and indicate; 1) those fall- and/or spring-sown seedlings where the herbicide has been safely applied at rates indicated without stunting or germination reduction (x); 2) herbicides that appear to be promising at rates indicated, but because of possible phytotoxic problems implied in some of our studies, these should be thoroughly tested before using at your nursery (o); 3) herbicides that should not be used

at rates indicated because of severe phytotoxic damage (-). One herbicide that should be elaborated on is napropamide. Napropamide is used at the lower rate (1.5 lbs ai per acre) when the nursery soil has below 1 percent organic matter, otherwise the higher rate (3.0 lbs ai per acre) is normally used. Napropamide is safe to use post-seeding on most spring-sown conifer species tested, but caused severe stunting when applied post-seeding to fall-sown conifer species in the Lake States study. Napropamide applied post-germination to both spring- and fall-sown conifers caused no phytotoxic problems.

Weed control expressed in terms of hand-weeding time, or "how much time can herbicides save you versus hand-weeding" is one of the most important aspects of these studies. In the Great Plains study (Abrahamson 1981) on spring-sown species the post-seeding applications were as effective as the post-seeding plus post-germination applications for total season weed control. The Forest Regeneration Center in Oklahoma is an example (Abrahamson 1983) of the type of savings in time and money that can be expected from these herbicides when used in forest tree nurseries.

Hand weeding time at the Oklahoma Forest Regeneration Center during 1981 was reduced by an average of 80 percent for all herbicides applied only in the spring (Ps) while those applied in both the spring and a second application five to six weeks later (Ps + Pg) reduced hand weeding time by an average of 87 percent. Based on minimum wage of \$3.35 per hour, this would amount to an average gross saving of \$4,600 per acre of seedbed (without figuring in cost of herbicide or application costs) weeded six times with a mean weeding time of 283 man hours per acre untreated seedbeds at Norman (Abrahamson 1983).

SUMMARY

There have been numerous trials, studies and tests of various herbicides at many different nurseries that have demonstrated the safe and effective use of dcpa, napropamide, oxyfluorfen, diphenamid, bifenox, oxadiazon, trifluralin, and prometryn on various conifer and/or hardwood first year seedling nursery beds. These herbicides have reduced the time required to hand-weed nursery beds by 80-87 percent when applied at sowing time alone or with a second application four to six weeks later. Over \$4,000-\$7,000 per acre of seedbed could be saved by using these herbicides over hand-weeding alone.

However, the safety and effectiveness of any herbicide should be tested at each nursery before operational use. These herbicide trials are urged because there is a strong possibility of differential results from varied interactions of different mixtures of tree and weed species, soil and climatic factors, and cultural practices at different nurseries. If a particular herbicide has never been used at your nursery, several years of trials are advisable because of variations in

effects caused by different weather conditions. Trials should include "double doses" to evaluate the safety limits on crop seedlings and leave an untreated control to properly evaluate the effects of the herbicide.

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TABLE 2: Phytotoxic effects of herbicides tested on first year loblolly, shortleaf and Austrian pine nursery beds.

LOBLOLLY PINE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		o	x	o
trifluralin	*		x		
napropamide & bifenox	*		o	x	o

SHORTLEAF PINE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
napropamide	*		x		
oxyfluorfen	*		x		
bifenox	*		x		
napropamide & bifenox	*		x		

AUSTRIAN PINE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		o	x	o
diphenamid	*		x	x	x
bifenox	*		o	x	o
trifluralin	*		x		
napropamide & bifenox	*		o	x	o

x = no phytotoxic effects at nurseries tested.

o = some phytotoxic effects at one or more nurseries where tested requires additional trials before operational use.

- = severe phytotoxic effects, Do Not Use.

TABLE 3: Phytotoxic effects of herbicides tested on first year ponderosa and Scotch pine nursery beds.

PONDEROSA PINE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		x	x	x
oxadiazon	*		x	x	x
trifluralin	*		x		
napropamide & bifenox	*		x	x	x

SCOTCH PINE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		x	x	x
napropamide	*		x	x	x
oxyfluorfen	*		x	x	x
diphenamid	*		x	x	x
bifenox	*		x	x	x
oxadiazon	*		x	x	x
trifluralin	*		x	x	x
prometryn	*		x	x	x

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested
requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 4: Phytotoxic effects of herbicides tested on first year eastern red cedar, and white cedar nursery beds.

EASTERN RED CEDAR

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	x	x	x
oxyfluorfen		*	x	x	x
diphenamid		*	x	x	x
bifenox		*	o	x	o
oxadiazon		*	x	x	x
trifluralin		*	x		
napropamide & bifenox		*	o	x	o

WHITE CEDAR

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	o	x	o
napropamide		*	o	x	o
oxyfluorfen		*	-	x	-
diphenamid		*	x	x	x
bifenox		*	-	x	-
oxadiazon		*	x	x	x
trifluralin		*	x		

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested
requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 5: Phytotoxic effects of herbicides tested on first year black walnut, and pecan nursery beds.

BLACK WALNUT					
Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	o	x	o
oxyfluorfen		*	o	o	o
diphenamid		*	x	x	x
bifenox		*	x	x	x
oxadiazon		*	x	x	x
trifluralin		*	x		

PECAN

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	x	x	x
bifenox		*	x	o	o
prometryn		*	x	o	o
napropamide & bifenox		*	x	o	o

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 6: Phytotoxic effects of herbicides tested on first year euonymus, and hackberry nursery beds.

EUONYMUS

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*	x	x	x
napropamide		*	x	x	x
diphenamid		*		o	
oxadiazon		*		x	
bifenox		*	o		
prometryn		*	o		
napropamide & bifenox		*	o		

HACKBERRY

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa		*		-	-
napropamide		*		x	
diphenamid		*	o	x	o
oxadiazon		*		x	

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 7: Phytotoxic effects of herbicides tested on first year lacebark elm, and sycamore nursery beds.

LACEBARK ELM

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		O	X	
napropamide	*		O	X	O
oxyfluorfen	*		-	X	-
diphenamid	*		-	O	-
bifenox	*		-	O	-
oxadiazon	*		-	X	-
prometryn	*		-	-	-
trifluralin	*		O	-	-
napropamide & bifenox	*		-	O	-

SYCAMORE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		-	X	-
napropamide	*		O	X	-
oxyfluorfen	*		-	X	-
diphenamid	*		O	X	O
bifenox	*		-	O	-
oxadiazon	*		-	X	-
prometryn	*		-	-	-
trifluralin	*		O	-	-
napropamide & bifenox	*		-	O	-

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 8: Phytotoxic effects of herbicides tested on first year redbud, catalpa, and silver maple nursery beds.

REDBUD

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		X	X	X
napropamide	*		-	X	-
diphenamid	*			X	
bifenox	*		O	O	O
oxadiazon	*			X	
prometryn	*		X		
trifluralin	*		O		
napropamide & bifenox	*			O	

CATALPA

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*			X	X
napropamide	*		X	X	X
diphenamid	*			X	
oxadiazon	*		X	X	
prometryn	*				
trifluralin	*		-		

SILVER MAPLE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination
dcpa	*		-	X	-
napropamide	*		X	X	X
oxyfluorfen	*		-		-
diphenamid	*		-	O	-
bifenox	*		-	O	-
oxadiazon	*			X	-
prometryn	*		X	-	-
trifluralin	*		-		-
napropamide & bifenox	*		-	O	-

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 9: Phytotoxic effects of herbicides tested on first year green ash, Russian olive, and black locust nursery beds.

GREEN ASH						
Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination	
dcpa	*		x	x	x	
napropamide	*		x	x	x	
diphenamid	*		x	x	x	
bifenox	*		o	o	o	
prometryn	*		x			
oxadiazon	*			x		
trifluralin	*		o			
napropamide & bifenox	*		-	o	-	

RUSSIAN OLIVE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination	
dcpa	*		x	x	x	
napropamide	*		x	x	x	
diphenamid	*		x	x	x	
bifenox	*		-	x	-	
trifluralin	*		x			
napropamide & bifenox	*		-	x	-	

BLACK LOCUST

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination	
dcpa	*			x	x	
napropamide	*		x	x	x	
bifenox	*		o	o	o	
prometryn	*		o			
oxadiazon	*			x		
trifluralin	*		-			
napropamide & bifenox	*			o		

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested
- requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 10: Phytotoxic effects of herbicides tested on first year baldcypress, and osage-orange nursery beds.

BALDCYPRESS

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination	
dcpa	*		x	x	x	
napropamide	*		x	x	x	
bifenox	*		x	o	o	
oxadiazon	*			x		
prometryn	*		o			
trifluralin	*		x			
napropamide & bifenox	*			o		

OSAGE-ORANGE

Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination	
dcpa	*		x	x	x	
napropamide	*		o	x	o	
bifenox	*		o	o	o	
oxadiazon	*					
prometryn	*		x	x		
trifluralin	*		o			
napropamide & bifenox	*			o		

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested
- requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 11: Phytotoxic effects of herbicides tested on first year mulberry, and autumn olive nursery beds.

MULBERRY						
Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination	
dcpa	*		o	x	o	
napropamide	*		-	x	-	
bifenox	*		-	o		
oxadiazon	*			x		
prometryn	*		-			
trifluralin	*		x			
napropamide & bifenox	*			o		

AUTUMN OLIVE						
Herbicide	Spring Sown	Fall Sown	Post-Seeding	Post-Germination	Post-Seeding & Germination	
dcpa	*		x	x	x	
napropamide	*		x	x	x	
bifenox	*		x	x	x	
oxadiazon	*			x		
prometryn	*		x			
trifluralin	*		x			
napropamide & bifenox	*			x		

x = no phytotoxic effects at nurseries tested.
o = some phytotoxic effects at one or more nurseries where tested
- requires additional trials before operational use.
- = severe phytotoxic effects, Do Not Use.

TABLE 12: Nursery summary of tree species and herbicides utilized in the Great Plains and Northern United States nursery herbicide studies from 1978 to 1987.

Nursery (Ownership)	Species Studied	Sown F/S	Herbicides Tested
Oklahoma Forest Regeneration Center [Norman Nursery] (State of Oklahoma)	Austrian Pine	S	DCPA
	Loblolly Pine	S	bifenox
	Shortleaf Pine	S	oxyfluorfen
	East. Red Cedar	F	trifluralin
	Black Locust	S	diphenamid
	Sycamore	S	napropamide
	Lacebark Elm	S	napropamide+bifenox
	Hackberry	F	oxadiazon
	Euonymus	F	prometryn
	Russian Olive ¹	F	butralin
	Silver Maple	S	chloramben ¹
	Mulberry	S	chloroxuron ¹
	Pecan	F	
	Catalpa	S	
	Redbud	S	
	Autumn Olive ¹	S	
	Green Ash ¹	S	
	Baldcypress ¹	S	
	Osage-orange ¹	S	

¹ Tested only one year or less.

Use of Sulfur to Correct Soil pH¹

Donald H. Bickelhaupt²

Abstract.-- The addition of 1780 lbs/ac of sulfur plus 1780 lbs/ac of sulfur as sulfuric acid resulted in a temporary decrease in soil pH. Seedling quality variables of Norway spruce were related to soil pH at time of sowing.

INTRODUCTION

The New York State Department of Environmental Conservation's Saratoga Tree Nursery, located at Saratoga Springs, New York, currently produces four to five million bareroot conifer seedlings annually (Scholtes 1985). The 100 acre nursery is located on deep loamy sand (80 to 90% sand with 5 to 10% clay). In the past 10 years the nursery has experienced problems in producing high quality seedlings of some species in some sections of the nursery. Problems encountered are poor seed germination, early seedling survival and many of the seedlings grown were stunted and chlorotic (Plumley 1986).

Between 1973 and 1977, the problem areas had received two to 12 inches of composted horse manure, including barn sweeping. This organic material was applied to the sandy soil to improve cation exchange, moisture holding capacity, and the amount of available nutrients. Laboratory analysis of several samples of material applied in 1973 indicated that the pH of the material was 8.16. Elemental analysis indicated that the material was very heterogeneous. Calcium and magnesium

concentrations averaged 3.6% and 1.7%, respectively. The concentrations of nitrogen, phosphorus and potassium were 0.8%, 0.2% and 0.7%, respectively. The high pH, and high concentration of calcium and magnesium were the results of lime being sprinkled daily on the floors of the stables to control the odor of urine.

A single, six inch application of composted horse manure in 1974, to one section of the nursery, increased the soil organic matter from 5.0% to 8.0% during the three years following application. The organic matter concentration had returned to approximately pre-treatment level by 1982. Soil pH increased from 5.7 to 7.2 as a result of the single, six inch application of manure. Soil pH was 7.0 twelve years after applying manure.

Soil pH above the recommended range of 5.5 to 6.0 is a concern for nursery managers because of potential problems with damping-off and nutrient imbalance. Damping-off is favored in cool and wet, neutral to basic soils containing large amounts of organic matter (Manion 1981). Nutrients, such as potassium and ammonium, become fixed in soils with a high pH and are, therefore, unavailable to plants. However, phosphorus availability is greatest when soil pH is between 6.0 and 7.0. Solubility of micronutrients increases with acidity and become toxic when soil pH is too low (Tinus 1980). Therefore, soil pH should be maintained within the range where nutrients are available for plant growth but the micronutrients are not at toxic levels.

Some conifer species are intolerant to soil pH above 6.0. Mean total dry

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weight of red pine (*Pinus resinosa* Ait.) has been shown to decrease as soil pH increased from 5.4 to 7.8 (Armson and Sadreika 1979). The weight of shoots and roots of greenhouse grown Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), was greatest when soil pH was 5.5 (van den Driessche 1979). Height growth of Norway spruce (*Picea abies* (L.) Karst.) has been shown to be related to soil pH with the tallest seedlings being produced in soil with a pH of 4.5 (Benzian 1965). Soil pH must be maintained within the recommended range of the species to produce an adequate number of high quality seedlings per unit area.

Sulfuric acid has been shown to be more effective than granular sulfur in reducing soil pH but the results are not permanent (van den Driessche 1969). In contrast, sulfur reacts slowly with the soil to reduce soil pH but the change is considered permanent (Tinus 1980). Utilizing this information, a study was established in the problem areas at the Saratoga Tree Nursery in an attempt to reduce soil pH and improve seedling quality. The application of a combination of sulfuric acid and granular sulfur was considered as a possible method to quickly reduce soil pH and maintain the soil pH between 5.5 and 6.0.

Use of Sulfur to Reduce Soil pH

The amount of sulfur required to reduce soil pH to a certain value varies with initial pH and the amount of colloidal material in the soil. In general, an application of 500 lbs/ac of granular sulfur is expected to decrease soil pH by 0.5 units in the surface six inches of sandy nursery soils (White et al. 1980). To change soil pH from 7.5 to 6.5, the Western Fertilizer Handbook (1980) recommends the addition of 500, 800 and 1000 lbs/ac of sulfur to a sandy, loam and clay soil, respectively. Stoeckeler and Arneman (1960) suggested that 870 lbs/ac of sulfur would be needed to lower the pH of a silt loam soil from 7.0 to 6.0 and 1525 lbs/ac of sulfur would be required to lower the soil pH from 7.0 to 5.5. To prevent detrimental effects to seedlings, the application of sulfur to a sandy nursery soil should not exceed 750 lbs/ac (Armson and Sadreika 1979).

METHODS

Study plots had received a single six inch application of composted horse manure in 1974. The soil pH increased from 5.7 to 7.2 and remained above 6.9 until 1983 as a result of this single application (Table 1). In addition, the application of composted manure increased the level of organic matter to over 8% and the concentration of exchangeable calcium was as high as 2500 ppm. In 1983 the organic matter concentration had decreased to 4.5%, whereas the concentration of exchangeable calcium remained high (1900 ppm). The cation exchange capacity was 10.2 meq per 100 g and the base saturation was 114% in 1983.

A single application of granular sulfur was applied at the rate of 0, 890, 1780, 2670 and 3560 lbs/ac in October 1984. During the same period, concentrated sulfuric acid was applied at the rate of 890 and 1780 lbs/ac of

Table 1. Effects of applying six inches of composted lime-treated horse manure on soil properties at the Saratoga Tree Nursery, New York.

Year	pH	OM ----	N %	P -----	K -----	Ca ppm	Mg -----
1974 ¹	5.7	3.6	0.06	83	28	396	31
1975	7.3	9.1	0.21	297	462	1216	338
1976	7.0	8.4	0.21	250	210	1426	355
1977	6.9	9.1	0.22	278	178	2509	549
1983	7.1	4.5	0.15	230	76	1900	231

¹ Horse manure was applied after the 1974 samples were collected.

sulfur. In addition, two combination treatments were established with granular sulfur and sulfuric acid each being applied at the rates of 890 and 1780 lbs/ac of sulfur. Each treatment was replicated three times. Norway spruce seeds were sown eight months after the application of sulfur.

Soil samples of the surface six inches were collected before treatments were applied, at time of sowing Norway spruce seeds, at the end of each growing season, and during the spring of the second growing season. Number of seedlings per foot of seedbed was determined in October, 1985 and October, 1986. Seedlings were lifted from the seedbeds in October, 1986, and measured for total height, root collar diameter and root volume (Burdett 1979). Additional seedlings were lifted in April, 1987, and measured for total height and root collar diameter. Ten seedlings from each nursery treatment plot were used for root growth capacity determination in April, 1987. Root growth capacity was determined by counting the number of white root tips per seedling after growing in the greenhouse for 28 days (Ritchie 1985).

RESULTS

Soil pH in the study area was 6.5 before treatments were applied. This soil pH was lower than the observed 6.8 to 7.0 found in other parts of the problem area because of the application of 840 lbs/ac of sulfur in the spring before the study was established. At time of treatment, the organic matter concentration was 3.0%; cation exchange capacity was 7.2 meq per 100 g; and concentrations of exchangeable calcium and magnesium were 1097 and 138 ppm, respectively. The base saturation was 92%.

A significant decrease in soil pH was observed eight months after sulfur application (Table 2). The application of 1780 lbs/ac of granular sulfur plus 1780 lbs/ac of sulfur as sulfuric acid resulted in further lowering soil pH compared to the other sulfur treatments and was the only treatment to reduce the soil pH to the desired range. After 23 months, the higher combination treatment of sulfur plus sulfuric acid still had a significantly lower soil pH as compared to the control (Table 2).

Table 2. Changes in soil pH of treatment plots as a result of applying sulfur and sulfuric acid at the Saratoga Tree Nursery, New York.

Treatment		Months since treatment				
Sulfur	Acid ¹	0 ²	8	12	20	23
(lbs/ac)		pH				
0	0	6.5 a ³	6.7 a	6.9 a	6.8 a	6.9 a
890	890	6.5 a	6.3 b	6.7 ab	6.6 ab	6.7 ab
890	0	6.5 a	6.3 b	6.4 abc	6.8 a	6.7 ab
0	890	6.5 a	6.3 b	6.4 abc	6.7 a	6.7 ab
1780	0	6.5 a	6.3 b	6.2 bcd	6.6 ab	6.5 ab
2670	0	6.7 a	6.2 b	6.2 bcd	6.5 ab	6.5 ab
3560	0	6.6 a	6.0 b	6.1 cd	6.5 ab	6.4 ab
0	1780	6.5 a	6.0 b	6.2 bcd	6.5 ab	6.6 ab
1780	1780	6.5 a	5.5 c	5.6 d	6.1 b	6.1 b

¹ The acid treatment is lbs/ac of sulfur as sulfuric acid.

² Month 0 is at time of treatment.

³ Values followed by the same letter within a column are not significantly different at P = 0.05.

Seedbed density at the end of the first growing season was influenced by the application of sulfur and sulfuric acid (Table 3). The plots that received sulfuric acid had significantly more seedlings per foot of seedbed compared to the control plots.

One beneficial aspect of many nursery soil amendments is the improvement in seedling quality. After two growing seasons seedlings growing in the plots which had received sulfur or sulfuric acid were significantly taller than the seedlings grown in the control plots (Table 4). Seedlings from the plots that received the heavier application of sulfur plus sulfuric acid were almost twice as tall as seedlings from the control plots. This mean total height represents all seedlings in the plot, including the culls.

Seedling root collar diameter at the end of the second growing season was also related to the application of sulfur (Table 4). The seedlings in plots receiving the higher rate of granular sulfur plus sulfuric acid had significantly larger root collar diameters than those in plots which received only sulfur or sulfuric acid. Seedlings in the control plots had the smallest root collar diameters.

Table 3. Seedlings per foot of seedbed as influenced by the addition of sulfur and sulfuric acid at the Saratoga Tree Nursery, New York.

Treatment		Seedlings per foot of seedbed	
Sulfur	Acid ¹	1-0	2-0
(lbs/ac)			
0	1780	120 a ²	111 a
2670	0	100 ab	99 ab
1780	1780	99 ab	99 ab
0	890	96 b	95 abc
890	890	95 b	88 abc
890	0	86 bc	86 abc
3560	0	80 bc	80 bc
1780	0	64 cd	69 cd
0	0	53 d	53 d

¹ The acid treatment is lbs/ac of sulfur as sulfuric acid.

² Values followed by the same letter within a column are not significantly different at P = 0.05.

Root volume of the seedlings in plots receiving the higher rate of granular sulfur plus sulfuric acid was significantly greater than the control plots (Table 4). The heavier application rate of granular sulfur plus sulfuric acid produced more new roots tips than the control and, therefore, had a higher root growth capacity (Table 4).

Morphological measurements of seedling quality were related to soil pH at time of sowing Norway spruce seeds, but not with soil pH at the end of the first growing season or during the second growing season. Variables strongly correlated with soil pH at time of sowing were seedling height, root collar diameter and root growth capacity. The only variable weakly correlated with soil pH at the time of sowing was root volume.

Seedlings lifted in the fall of 1986 and spring of 1987 were graded to a minimum standard (root collar diameter being 0.09 inches and height being 3.5 inches) (Reese and Sadreika 1979). This grading indicated that over 60% of the seedlings grown in all sulfur plots were plantable, whereas less than 40% of the seedlings grown in the control plots were acceptable (Table 5). The heavier application of granular sulfur plus sulfuric acid resulted in the largest percentage of large and medium size seedlings and the smallest percentage of cull seedlings. The control plots had the largest percentage of culls. The percentage of large, medium and cull seedlings was strongly correlated to soil pH at time of sowing.

Another beneficial aspect of nursery soil treatment is the increase in the number of plantable seedlings per unit area. The largest number of plantable seedlings was produced in the plots that received the heavier application of granular sulfur plus sulfuric acid (Table 6). The lowest number of acceptable seedlings was produced in the control plots. The number of seedlings per foot of seedbed and the cull percentage have been shown to be related to sulfur treatment and soil pH at time of sowing Norway spruce seeds.

Table 4. Morphological characteristic of 2-0 Norway spruce seedlings as influenced by the application of sulfur and sulfuric acid treatments at the Saratoga Tree Nursery, New York.

Treatment		Height (in)	Diameter (in)	Root volume (cm ³)	Number of white root tips
Sulfur	Acid ¹				
1780	1780	6.14 a ²	0.100 a	2.28 a	100 a
0	1780	5.41 ab	0.086 bc	1.48 cd	79 ab
3560	0	5.29 bc	0.090 b	2.01 ab	49 bc
890	0	5.22 bc	0.086 bc	1.88 abc	52 bc
2670	0	5.01 bc	0.080 cd	1.17 bcd	65 bc
0	890	4.81 bc	0.079 cd	1.48 abc	59 bc
890	890	4.73 bc	0.082 cd	2.00 ab	63 bc
1780	0	4.46 bc	0.077 d	1.94 abc	53 bc
0	0	3.15 d	0.063 e	1.45 d	44 c

¹ Acid treatment is lbs/ac of sulfur as sulfuric acid.

² Values followed by the same letter within a column are not significantly different.

Table 5. Percentage of seedlings by size class as influenced by the application of sulfur and sulfuric acid treatments at the Saratoga Tree Nursery, New York.¹

Treatment		Large	Medium	Small	Cull
Sulfur	Acid ²				
(lbs/ac)		Percent			
1780	1780	20.8 a ³	26.8 a	32.9d ¹	19.5 c
3560	0	13.8 b	14.8 bc	45.0 abcd	26.4 bc
0	1780	8.5 bc	16.1 b	42.3 abcd	33.1 bc
890	0	6.5 cd	15.8 bc	44.2 abcd	33.5 bc
2670	0	6.4 cd	13.4 bc	49.4 abc	30.8 bc
0	890	6.1 cd	14.4 bc	41.4 bcd	38.1 b
890	890	6.0 cd	8.0 bcd	58.4 a	27.6 bc
1780	0	3.0 cd	7.1 cd	53.0 ab	36.9 bc
0	0	0.6 d	2.4 d	34.6 cd	62.4 a

¹ Large size seedlings: >0.11" diameter and >7.5" height
 Medium size seedlings: >0.10" diameter and >6.3" height
 Small size seedlings: >0.09" diameter and >3.5" height
 Cull seedlings: <0.09" diameter or <3.5" height

² Acid treatment is lbs/ac of sulfur as sulfuric acid.

³ Values followed by the same letter within a column are not significantly different.

DISCUSSION

Results observed from the application of sulfur and sulfuric acid at the Saratoga Tree Nursery revealed that the soil pH at time of sowing and germination of Norway spruce seeds was important in producing quality seedlings. With the expectation of root

volume, all variables of seedling quality were affected by the soil pH at the time of sowing. The higher application rate of sulfur plus sulfuric acid yielded the lowest soil pH and the highest quality of seedlings.

These results differed from those observed at the Orono Nursery, located near Toronto, Ontario (Mullin 1964). At

the Orono nursery sulfur was applied at 0, 750, 1500 and 2250 pounds per acre, and at the end of three years, soil pH was reduced from 7.4 to 6.5, 6.0, 5.3 and 5.0, respectively. The reduction in soil pH of the control plots at the Orono Nursery may have been the result of the application of ammonium sulfate fertilizer the first year and ammonium nitrate the remaining two years of the study. With the exception of the 2250 lbs/ac treatment, seedlings produced in sulfur treated plots were taller, thicker (larger root collar diameter), and heavier with a lower top-root ratio than seedlings grown in the control plots. The 2250 lbs/ac treatment resulted in increased mortality of seedlings at the end of the first growing season.

The different results obtained in reducing soil pH with the high application rates of sulfur in the Ontario study and the Saratoga study may be related to the differences in cation exchange capacity and buffering capacity of the soils. Another contributing factor is that the organic matter applied at the Saratoga Tree Nursery contained large amounts of calcium and magnesium and served as a buffering agent. In fact, the application of six inches of composted lime-treated horse

manure was equivalent to applying 3.5 tons per acre of lime.

At the Saratoga Tree Nursery the reduction of soil pH by most treatments, however, was only for a short duration. The effect of the addition of 3560 lbs/ac of granular sulfur on soil pH is undetectable 20 months after application. In contrast, the application of 1780 lbs/ac of granular sulfur plus 1780 lbs/ac of sulfur as sulfuric acid showed a reduction of soil pH for at least 23 months. Primarily analyses indicate a treatment of 1780 lbs/ac sulfur plus 1780 lbs/ac sulfur as sulfuric acid is an acceptable method of lowering soil pH to obtain high quality seedlings.

Most of the study plots at the Saratoga Nursery that received sulfur or sulfuric acid had seedbed densities above the recommended 60 to 70 seedlings per foot of seedbed (Richards et al. 1973) at the end of the second growing season. The addition of sulfur plus sulfuric acid combined with the operational sowing rate created conditions for high seedbed density. Consequently, individual seedling weight may decrease as seedbed density increases because of decreased seedling branching (Richards et al. 1973). By using the higher sulfur plus sulfuric acid treatment in conjunction with a lower sowing rates, desirable seedbed densities of high quality seedlings may be produced at a reasonable cost. A cost-benefit analysis needs to be conducted to examine economic benefits.

Results of the Saratoga study were also similar to other studies where the number and size of seedlings increased as a result of applying sulfuric acid (Hartley 1917). In fact, the application of sulfuric acid provided two benefits: (1) increased the soil acidity and (2) acted as a soil sterilizer. Before organic fumigants were developed, sulfuric acid was often used as a soil sterilizer (Stoeckeler and Slabaugh 1965). High populations of *Fusarium* reported by Plumley (1986) at the Saratoga Nursery may have been controlled by the application of sulfuric acid.

Although heavy applications of sulfur and sulfuric acid improved seedling quality at the Saratoga Tree Nursery, I must stress that these heavy application rates may not be acceptable at all nurseries and all species. Testing with small plots are needed to determine beneficial rates and any potential adverse effects.

Table 6. Number of plantable seedlings per foot of seedbed as influenced by the application sulfur and sulfuric acid at the Saratoga Tree Nursery, New York.

Treatment		Number of seedlings
Sulfur (lbs/ac)	Acid ²	
1780	1780	79 a ²
0	1780	74 ab
2670	0	68 abc
890	890	64 abc
3560	0	59 bcd
0	890	56 bcd
890	0	54 cd
1780	0	42 d
0	0	21 e

¹ Acid treatment is lbs/ac of sulfur as sulfuric acid.

² Values followed by the same letter within a column are not significantly different.

CONCLUSIONS

1. The effect of applying six inches of composted lime-treated horse manure resulted in an increase in soil pH; a condition that has persisted for at least 12 years.
2. The heavy application of sulfur resulted in a significant decrease in soil pH eight months after application. The greatest decrease in soil pH was achieved with the application of 1780 lbs/ac of granular sulfur plus 1780 lbs/ac of sulfur as sulfuric acid.
3. No significant differences were detected in soil pH twenty months after the application of sulfur or sulfuric acid. The combination of sulfuric acid plus sulfur decreased soil pH for at least 23 months.
4. The application of sulfur resulted in larger seedlings. The largest seedlings were produced in plots receiving the higher application rate of granular sulfur plus sulfuric acid.
5. Measures of seedling quality strongly correlated with soil pH at time of sowing Norway spruce seeds were height, root collar diameter and root growth capacity.
6. The application of sulfur reduced the percentage of cull seedlings and increased the number of seedlings per foot of seedbed.

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Certified Vendor Program¹

Thomas G. Boggus²

Abstract.--With demands for timber resources and the cost of reforestation rising, inconsistency in planting standards, and several important groups impacted by the success or failure of each planting effort, the Texas Forest Service, in 1982, initiated its Certified Vendor Program. Now, through specific guidelines, inspection and training, more energy can be spent reforesting new NIPF lands, knowing current cases have been properly planted.

INTRODUCTION

The common goal of everyone involved in reforestation is to successfully establish a stand of healthy trees in the field. No matter what facet of the process you may be involved with, all efforts are concentrated at this one goal. As the demand for the resource continues to rise along with the costs of reforestation, the ability to reach this goal is becoming more and more challenging.

During the planting season of 1987, 1.12 million acres were artificially reforested in the southeastern United States on nonindustrial private forest lands. Using an estimated cost per acre of \$115.00 for site preparation, seedlings and labor, that acreage figure represents an annual investment of over 128 million dollars in reforestation. The East Texas contribution amounts to 22,500 acres and \$1.67 million annually with almost equal amounts being invested by the landowners and the three cost-sharing programs available in the state. These figures offer striking evidence that mistakes resulting in increased seedling mortality are extremely costly. In 1982, the Texas Forest Service began implementing a Certified Vendor Program in an effort to reduce mistakes during the time the trees leave the nursery and are planted in the field.

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REASONS FOR THE PROGRAM

Resource Demands

Results of the recently completed U.S.F.S. Forest Survey of East Texas reveal that removals of softwood have exceeded growth over the last few years (Fig. 1). Much of this trend, along with the potential for changing it, can be explained by looking to the nonindustrial private landowner (NIPF). This group owns approximately 60% of the commercial Forest land in Texas and yet has the poorest record historically in reforesting following a harvest.

Currently, only one acre in nine is reforested by NIPF landowners in Texas (Fig. 2). Given that figure, it is imperative that this important "acre" survive after being planted. Thus, one reason for the Certified Vendor Program is to improve the odds of survival through proper handling and planting methods. Of course, promotional and educational efforts continue to work towards seeing more of the other "eight acres" planted.

Program Consistency

A second reason for the vendor program was the need to bring consistency to the NIPF regeneration program. Prior to beginning the program, there were years where we were losing 8,000-12,000 acres per year when it could not be explained away by "dry weather." Seedling counts across East Texas revealed 500-550 seedlings per acre were being planted versus the 726 per acre called for in the management plans. Foresters had as many different ways of

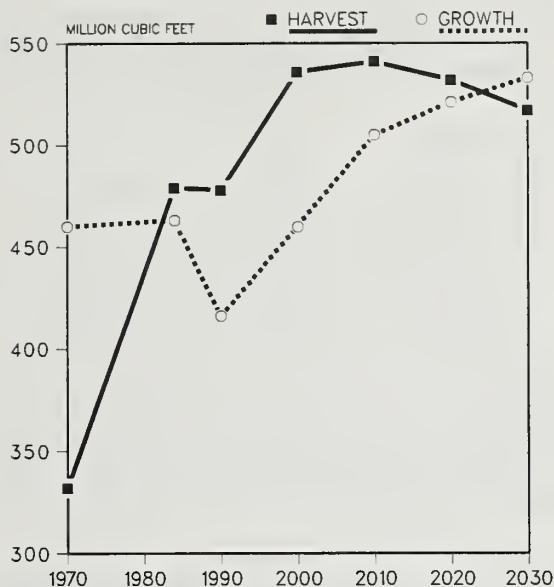


Figure 1.--Historic plus projected harvest versus growth figures for East Texas (USDA, 1987).

inspecting the jobs as the agency had foresters! Not to mention there was no standard means of comparing one vendor or job to the next and, therefore, good vendors were not being rewarded for excellence and poor vendors were taking advantage of the system, the agency and the landowners.

Groups Impacted

Another important reason for the Certified Vendor Program is the group of people impacted by the success or failure of a tree planting job. This group includes landowners, funding institutions and planting vendors.

More than any other group, tree planting will have the greatest impact on landowners. Not only do they invest their hard earned savings into the project, they also make the decision to invest 20-30 years of their lives into these 6 to 8 inch tall trees. Survival is the first hurdle to pass but the next 19 risk-filled years are theirs to bear as well. The vendor program is aimed at helping clear that first hurdle with vigorous, healthy trees.

Since nearly all NIPF landowners in Texas take advantage of one of the three programs currently operating in the state that share the financial burden of reforestation, these funding institutions are also impacted by the success or failure of a job. Limited funds and the continued rise in reforestation costs mandate that the tracts requiring re-planting be kept to a minimum. The Certified Vendor Program helps reduce the amount of re-planting caused by poor planting methods.

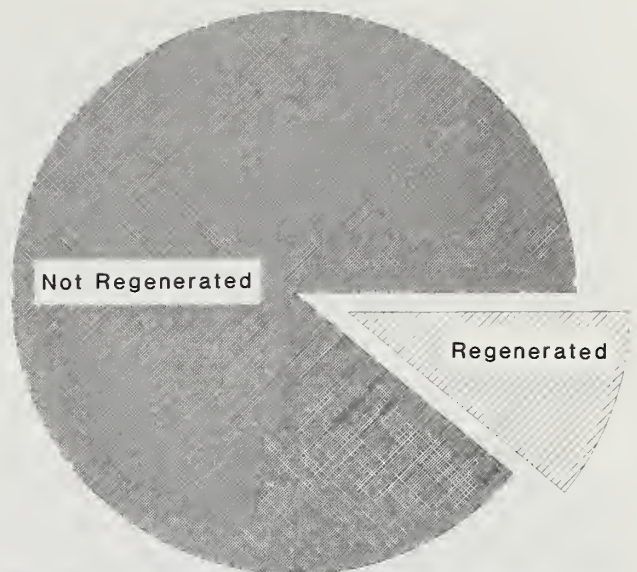


Figure 2.--Comparison of NIPF acres regenerated following harvests.

Tree planting vendors themselves are also impacted by their own planting jobs. A vendor has his/her livelihood and reputation riding on each planting effort. Since its inception, many vendors have commented on how this quality control type program is like having a "silent supervisor" on each NIPF tract their crews plant.

Cumulative Effect

Dr. S. J. Rowan (1987) recently released the results of study on the effects of tender loving care (TLC) from lifting to outplanting on survival. Although TLC produced positive results throughout the process, he concluded that nothing had a greater impact on survival than did proper handling and care during the actual transplanting in the field. This cumulative effect on survival is further magnified when consideration is given to the rather unique geographic location of Texas' commercial forestland. Planting pines in the western fringe area of the Great Southern Yellow Pine Forest demands extra care and, thus, the Certified Vendor Program.

KEYS TO SUCCESS

Having established the obvious need for the vendor program, the next step is to develop a clear set of objectives. The three main objectives of the Texas Certified Vendor's Program are:

1. Insure quality reforestation
2. Develop a qualified vendor community
3. Allocate work fairly

The keys to the success or failure in reaching these objectives lie in the methods chosen to implement the program.

Insure Quality Reforestation

Quite obviously, the primary objective of the Certified Vendor Program from its inception was to deliver a quality reforestation effort to NIPF landowners. Moving to meet this goal, however, required more care and planning than would the other two. The keys here are to develop a good set of technical guidelines, implement a uniform method of inspecting the work and train the personnel responsible for carrying out the program on the ground.

Technical Guidelines

The beginning point to insuring a quality reforestation effort is for all parties involved to be working within the same framework. In Texas, we developed a set of technical guidelines covering the three main topics of site preparation, planting and timber stand improvement. Each topic is further broken down into smaller sections which spell out in detail what practices are permitted, how to carry them out and what the minimum limits of acceptability are for each practice. Every forester, technician and vendor is supplied with, or has access to, a copy of these guidelines so everyone knows, in advance, what is expected of them.

For example, here is how "reforestation" is further broken down into sections. There are seven sections which include planting rates, planting methods, seedling care, protection of seedlings, environmental considerations, vendor certification and vendor completion requirements. Everyone involved with reforestation on any given NIPF tract is working under the same rules and knows the consequences for breaking them. Of course, these guidelines are only good as long as there is some way to verify they are being complied with, which means on site inspections.

Inspection

The strength and credibility of the vendor program center around the inspection process. Almost every NIPF tract planted in East Texas is inspected by a trained tree planting inspection crew. These two-man crews systematically check 1/100th acre plots over an entire area, with the number of plots per tract dependent upon actual tract size (table 1).

Upon arrival at each plot site, the plot is numbered and marked with a wire flag in case it is necessary to return to that particular plot. Next, the total number of trees per plot are counted by using a 1/100th acre tape or rope and that number is recorded on a data sheet. Then the trees within the plot are checked for "above ground problems" (table 2) such as debris in the hole or planted too shallow. Finally, before

Table 1.--Number of plots taken based on the size of the tract and approximate distance between plots in Gunter's chains.

Tract Size (acres)	# of Plots	Dist. (chains)
0-60	1 per ac	3.25
61-90	1 per 2 ac	4.50
91+	1 per 3 ac	5.50

leaving a plot, two trees are carefully excavated outside of the plot itself to inspect for any below ground problems like severe root pruning or "J" rooting (table 2).

Table 2.--A list of specific above and below ground problems inspection crews look for at each plot.

Above Ground Problems	
Debris in hole	Cull seedlings
Too shallow	Too deep
Not packed	Unidentified

Below Ground Problems	
Excessive angle	"J" rooting
"L" rooting	Twisted roots
Pruned improperly	Cull seedlings

Before leaving the planting site, the inspection is completed by checking seedling bundles and counting and culling two bundles of seedlings, if possible. The bags are checked for species type to insure the right species is planted on each tract and the bag dates for when the bundles left the cold storage. Vendors have 14 days to either plant the trees or heel them in after the seedlings leave cold storage. Failure to do so results in bag confiscation and replacement seedlings must be furnished by that vendor. The seedling bundle count provides important information to the nursery as to how many plantable trees per bag are leaving the nursery. This is especially important since the data is received during lifting and grading so adjustments can be made as needed.

Since the inspection process is so important to the success or failure of the program, some means of "inspecting the inspectors" or quality control is vital. In Texas, we have quality control people in each management area whose job it is to spot check every inspection crew

working in their area. The crews never know where or when the quality check will be performed and poor job performance could mean a severe reprimand or their jobs.

Training

From the previous section it becomes apparent that a virtual army of inspectors is needed. That entails training this army initially and then continuing to update them on any changes from year-to-year plus refresher courses. The source of manpower for these inspectors came from our forest technician ranks who were, up to this point, primarily considered fire fighters. Their number one priority is still to suppress wildfires, however wildfire suppression does not require the bulk of their time except for generally short periods of time during the year.

Tree inspection training requires about three days to complete. The first day is spent in a classroom session reviewing the technical guides, plot procedure, mathematics involved in working up the data, and other matters concerning the inspection of a tree planting job. The next two days are spent in the field in "hands-on" type exercises with individual instruction at each station. Both the classroom and field exercises have exams the trainees must pass prior to becoming a certified inspector.

Develop a Qualified Vendor Community

Approximately 22,500 acres of NIPF lands are reforested annually in East Texas. Even though this level of planting pails in comparison with some other southeastern states, it is impossible for the Texas Forest Service personnel to plant this acreage and undesired, even if it were possible. Therefore, it is imperative that a qualified community of vendors be developed to handle the work. To begin to accomplish this, we must once again turn to training.

As stated, each vendor interested in planting trees in NIPF lands in East Texas is supplied with a copy of our technical guidelines. Additionally, we require a vendor to attend one of the day-long meetings held at different locations and dates during the fall. During these meetings, the vendors have

explained in detail the requirements of the program, technical guides, inspection process and other matters concerning planting season through a multimedia presentation and question-answer session. At the conclusion of every meeting, the vendors wishing to participate in the Certified Vendor Program sign an agreement stating they will plant according to the guidelines. The requirements are tough but fair and our list of vendors grows each year.

Allocate Work Fairly

The final objective to meet after everything else has been implemented is to find a means of allocating the work to the vendor community. The best method we have found is through the use of the sealed competitive bid system. Not only does this remove the agency from any bias in vendor selection, it also keeps reforestation costs down for the landowner due to vigorous competition. Landowners, not the Texas Forest Service, have the option to accept or reject the bids received on each tract. Since the vendors must meet minimum requirements under the program and vendors are not paid until these requirements are met, the landowner is assured of a quality planting job.

CONCLUSION

With the increasing demands for forest resources and planting mistakes resulting in reforestation failure becoming more costly, the Texas Forest Service has begun to take steps to meet both problems. In essence, we take this saying to heart, "you can achieve results two ways: expect it or inspect for it"! We expect a great deal from our own people and the vendors, but then we make inspections to insure we get it.

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Alternative Methods to Evaluate Root Growth Potential and Measure Root Growth¹

W. J. Rietveld and Richard W. Tinus²

Abstract.--This paper reports experiments that compared root growth potential (RGP) testing methods, methods of quantifying root growth, and diagnostic ability of test methods. Factors that affect root growth in RGP tests are discussed. New root growth and plant water potential patterns of jack pine seedlings in pot, hydroponic, and aeroponic culture were similar, but new roots appeared first in hydroponic and aeroponic culture. The simplest method of quantifying root growth is to measure the number of roots longer than a minimum length. Electronic measurement of root area index is fast and well correlated with root number and length, but the equipment cost makes it most suitable for large operations. Test method and test length may affect results. Fourteen-day pot and aeroponic culture tests of jack pine seedlings subjected to root exposure treatments accurately diagnosed the weakened seedlings, but the seedlings recovered in 28-day tests, especially in aeroponic culture. For new applications, it is recommended that preliminary screening tests be run to determine the most suitable testing conditions.

INTRODUCTION

Root growth potential (RGP) is the most important measurable attribute of physiological quality because it quantifies the ability of seedlings to initiate and elongate new roots promptly and abundantly after transplanting. RGP is unique because it integrates an array of physiological factors into a single biologically meaningful estimate of performance potential -- the ability to grow new roots. Much information has been published on RGP in the past few years. Available evidence to date indicates a strong relation between RGP and field survival and growth (Ritchie 1985). Factors that affect the development and expression of RGP were extensively reviewed by Ritchie and Dunlap (1980), the relation of new root growth to several seedling and environmental factors was discussed by Carlson

(1986), and the role of new root growth in the mechanism of transplanting stress was discussed by Sands (1984).

In contrast to most morphological quality measurements, which can be measured almost instantaneously, physiological quality attributes take time to measure (except for plant moisture stress). Consequently, it is not yet feasible to test stock and grade it physiologically before shipping. Until a faster method is available to estimate RGP, e.g. via a connection with cold hardiness (Ritchie 1985; Tinus, et al. 1986), we must be content to rely on present root growth tests to document RGP, and obtain the results in 2-4 weeks, usually after the seedlings have left the nursery.

Many people have hesitated to become involved in RGP testing because of: (1) equipment costs, (2) long test length, and (3) labor requirements and tedium of taking data. For the most part, these drawbacks are more imagined than real. The many variations on the original 28-day RGP test are summarized by Ritchie (1985). RGP tests may be shortened to as little as 7 days for certain species (Burdett 1979), and root growth may be quantified by new root number, length, volume, area index, or dry weight. In this paper we will focus on: (1) selection of methods to test the seedlings; (2) alternative methods to measure new root growth; and (3) the effects of testing

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method, test conditions, and test length on results.

COMPARISON OF TESTING METHODS

Although many different growing systems and media have been tried, the three main methods currently used to test seedlings are pot culture, hydroponic culture using an aquarium, and aeroponic culture using a root misting chamber. Pot culture is the traditional method (Stone 1955). It appears to be straight forward and inexpensive, but two important test conditions must be satisfied: (1) root temperature must be kept uniform, and (2) the growing medium must be well aerated. To provide a uniform root temperature, a growth room or water bath system is usually required, which raises the cost to a level comparable with other methods. Well-designed and relatively inexpensive hydroponic methods have recently been reported (DeWald et al. 1985, Palmer and Holen 1986). Hydroponic culture keeps the seedlings clean of growing medium, allows periodic observation of the progress of root growth, minimizes damage to new roots, and allows the test seedlings to be grown in fewer containers, while maintaining uniform root temperature and aeration within containers. It is important that aeration be gentle and uniform among containers, otherwise the agitation may inhibit root growth and increase variation. Aeroponic culture in a root misting chamber is another new technique. It was originally reported by Lee and Hackett (1976), refined by Harvey and Day (1983), and more recently refined by Rietveld and Tinus (1987). The root misting chamber has the same advantages as hydroponic culture, plus it is portable and provides a uniform temperature, humidity, and aeration environment for the roots in one container.

While developing the new root misting chamber, we needed documentation to show how the new device compares with existing methods for growing the test seedlings. To provide that documentation, we grew overwinter-stored 2+0 jack pine (*Pinus banksiana* Lamb) seedlings in pot culture, hydroponic culture, and aeroponic culture in the new root misting chamber, and compared new root production, among-seedling variation, and root size distribution. Potted seedlings were grown in a mixture of 1:1:1 sand/perlite/vermiculite with no fertilizer added. The hydroponic system consisted of tree holders laid across a large 20-cm-deep galvanized tank of water gently aerated through aquarium stones. The three growing systems were located in a growth room set at a constant 27° C temperature, 18 hour photoperiod, and light intensity of 165 $\mu\text{E}/\text{m}^2/\text{sec}$. The root misting chamber was also set at 27° C. Seedling root growth of 10 seedling samples was measured after 9, 11, 14, 16, 18, 21, 23, 25, and 28 days using a new root area index method (Rietveld and Tinus 1987). Number and length of new roots longer than 0.5 cm were also measured on day 28. Additionally, plant water potential of each test seedling was measured, using a pressure chamber,

at the same time root growth was measured. Data were subjected to analysis of variance and Bartlett's test of homogeneity of variances.

New root growth was observed first in the root misting chamber and in hydroponic culture on day 9, then in pot culture on day 11 (fig. 1). Although seedlings grown in the root misting chamber had consistently higher levels of new root growth, the data were statistically indistinguishable from the hydroponic and pot methods on all measurement days, due to high among-seedling variation. The variances of the three methods, compared for the overall test and for days 14, 21, and 28, were likewise indistinguishable.

Root size distributions on day 28 for seedlings tested by the three methods are shown in figure 2. Although the patterns are similar for roots less than 15 cm long, seedlings grown in the root misting chamber and hydroponic culture had more long roots, reflecting the earlier and faster rooting apparent in figure 1. The response may also reflect the lack of soil resistance to root elongation.

The pattern of plant water potential in test seedlings is shown in figure 3. Average potential of seedlings taken from the cooler on day zero was -0.5 bar. Within 1 day in the growth room, potential dropped (became more negative) to approximately -6 bars, bottomed at approximately -6.5 bars on day two, then gradually increased during the course of the test to the range of -3 to -4 bars. The increase in plant water potential was weakly correlated with the initiation of new roots ($r = -0.34$), and may be better explained by osmotic adjustment. There were no significant differences in plant water potential among the cultural methods on any of the measurement days.

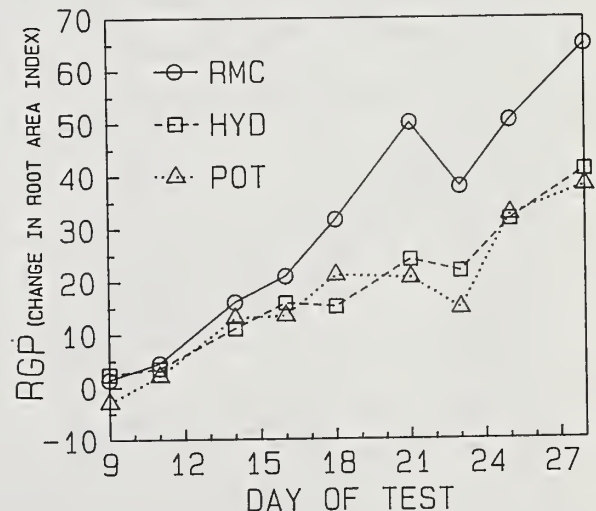


Figure 1. Root growth potential of 2+0 jack pine seedlings grown in aeroponic, hydroponic, and pot culture, quantified as change in root area index for nine test periods.

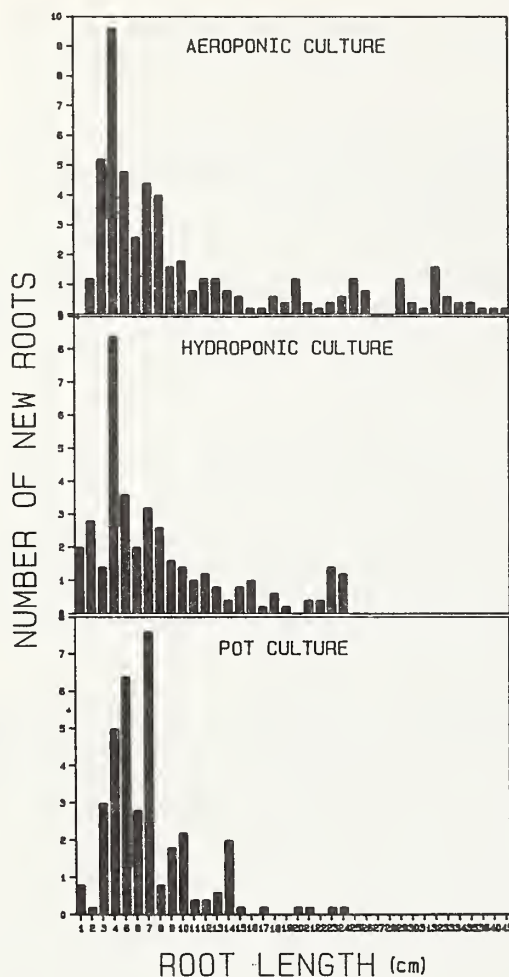


Figure 2. Size distribution of new roots of jack pine seedlings, on a per seedling basis, after 28 days of growth in aeroponic, hydroponic, and pot culture.

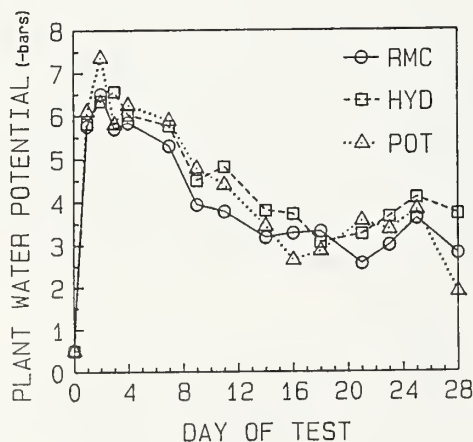


Figure 3. Plant moisture stress of 2+0 jack pine seedlings grown in aeroponic, hydroponic, and pot culture. Each point is the mean of 10 seedlings.

These data show that the three growing methods produce similar growth patterns for normal planting stock. Root growth was somewhat faster in the root misting chamber than in hydroponic or pot culture. For jack pine, 14 days appears to be the minimum test length to obtain an acceptable root growth response for evaluation.

COMPARISON OF METHODS TO MEASURE ROOT GROWTH

The task of quantifying new root growth may seem initially formidable when you look at a seedling that has up to 400 new roots on it, but the job is not as big as it looks. Researchers have devised many methods to lessen the task while still obtaining meaningful data. Originally both number of new roots and total length of new roots were measured. Eventually it was found that root number and root length are strongly correlated (Stone and Schubert 1959), so only number of roots longer than a minimum length was measured. Note, however that the correlation would be expected to decrease as test length increases because some of the new roots grow quite long (see fig. 2). Harvey and Day (1983) were the first to quantify new root growth in RGP tests by change in root area index using a Rhizometer (Morrison and Armson 1968), a photoelectric device developed for seedling morphology measurements in Ontario. Racey (1985) compared root measurement by root area index (using the Rhizometer), volume, and dry weight. He found strong correlations between the three quantification methods and the calculated area of new root tips, and recommended root volume because it was the easiest to measure. However, the Rhizometer has problems detecting new white roots at high light intensities (Racey 1985), and root volume determined by the Archimedes principle (measuring weight increase when the roots are dipped into a large beaker of water on a balance) has problems due to lack of repeatability of individual measurements (Ritchie 1985). A new root area index method for quantifying root growth in RGP tests was developed by the authors (Rietveld and Tinus 1987). The method is based on a microprocessor area meter (Delta-T Devices, Cambridge, England³), and involves placing an intact root system on a light box in view of a black and white TV camera. The image is scanned by the area meter, and a microprocessor totals all the line segments in the viewing area that are covered by roots. The method is very fast (up to 500 seedlings/day), but the equipment costs much more (\$3670) than that needed to count the new roots manually.

To provide documentation for the microprocessor root area index method, we conducted a test to determine the relation among new root growth measured by change in root area index,

³The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

counted number of new roots, and measured length of new roots. To compare the methods over a range of RGP, we gave 50 jack pine seedlings root exposures of 0, 10, 20, 30, and 40 min by placing them in a large forced-air oven at 40° C. The seedlings were grown in a root misting chamber located in a greenhouse with maximum air temperatures ranging between 18 and 28° C, minimum air temperature of 15.5° C, photoperiod extended to 18 hours with high pressure sodium lamps, and light intensity ranging from 300 to 800 $\mu\text{E}/\text{m}^2/\text{sec}$. The root misting chamber temperature was set at 27° C, which is favorable for jack pine. After 17 days, new roots >0.5 cm on each seedling were measured manually, and all new roots were measured by the root area index method. Root growth measurements were compared by linear regressions using individual seedlings as observations ($n=50$). The coefficients of determination (r^2) for change in root area index on total number of new roots and total length of new roots were 0.88 and 0.90, respectively (fig. 4). Total number of new roots was closely related to total

length of new roots ($r^2=0.93$). These strong relations indicate that measuring new root growth as change in root area index is a valid quantification method that provides a close estimate of actual root number and length.

Change in root area index may be a better estimate of rooting response than either root number or root length because (1) it measures all new roots, (2) it takes both root diameter and length into account, and (3) it detects root decrement as well as increment. However, the root area index method does not distinguish the origin of new roots and does not give any information on individual root size classes, i.e. the relative abundance of coarse and fine roots.

RGP TEST ENVIRONMENT AND SAMPLING

Although it is widely accepted that a uniform and favorable root environment is most important for conducting RGP tests, the shoot environment

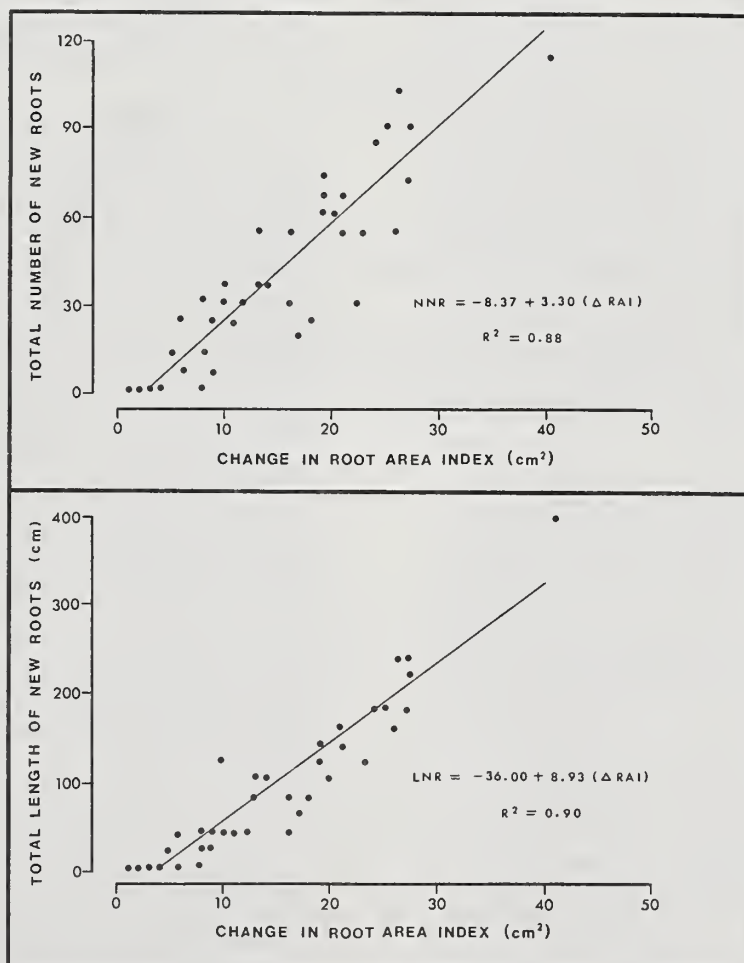


Figure 4. Regressions of root growth quantified by number of new roots (NNR) and length of new roots (LNR) on change in root area index (ΔRAI), measured on the same seedlings. $n=50$. Several points represent multiple seedlings, especially those with zero NNR or LNR.

should also be favorable and repeatable when a series of RGP tests are run and the results compared. Abod et al. (1979) found that RGP of *Pinus caribaea* Mov. and *P. kesiya* Royle ex Gordon seedlings was optimized at air and soil temperatures between 24 and 30° C, and light intensity of approximately 50% of full sunlight (500-750 $\mu\text{E}/\text{m}^2/\text{sec}$). The optimum temperature for seedling root growth of many North American species is near 20° C (Ritchie 1985). Root growth potential tests are commonly run at elevated root and shoot temperatures and extended photoperiods. These conditions are well beyond the normal environment when seedlings are transplanted, but test results are obtained in a shorter time. Significant seed source and family differences in optimum temperature for root regeneration have been documented within a species (Carlson 1986, DeWald and Feret 1985, Jenkinson 1980, Nambiar et al. 1982). Therefore, it is advisable to experiment with root and shoot temperatures, and test length to determine the most suitable conditions for the species being evaluated, as well as seedlot or family variation in response to temperature. If seedlot or family variation is significant, it may be useful to adjust RGP to a base temperature (e.g. 20° C) for comparison.

Another factor to consider is seedling size. Seedlings with higher root volume have higher RGP (Carlson 1986), so it is important that the sample tested represents the range of seedling sizes in the stock lot. Note that selecting seedlings of uniform size for testing RGP would give a biased estimate of RGP if the average size of the sampled seedlings was not the same as the mean size for the stock lot. To obtain a true random sample that represents the range of seedling size and condition in the seedlot, the seedlings to be tested must be sampled from many locations in the population.

For normal bed-run stock, we consider a sample size of 25 seedlings to be minimum because variation is often high in RGP tests (Ritchie 1985, Sutton 1983). Depending on the uniformity of the test plants and the precision desired, 50 seedlings or more may be necessary. Very uniform plant material, such as stock grown by family (e.g. from seed collected from a clone in a seed orchard), may require fewer test seedlings.

DIAGNOSTIC ABILITY OF THE TEST METHODS

An additional question that needs to be addressed is how do the methods compare in diagnosing stock that differs in vigor -- will the same conclusions be reached using different testing methods? To answer this question, we generated several levels of seedling vigor by subjecting jack pine seedlings from a common seedlot to root exposures of 0, 10, 20, 30, 40, and 50 min at 40° C in a large forced-air oven. We then assigned 15-seedling random samples to 14-day and 28-day RGP tests in the root misting

chamber and pot culture. The experiment was conducted in a large root misting chamber (0.9 m wide x 3.7 m long) located in a greenhouse under the same environment as the previous experiment. Potted seedlings were suspended in the root misting chamber so that the root temperature in the pots was maintained at the same temperature as the misting chamber. New root growth was quantified by the root area index method described above.

The results were quite surprising. At 14 days the root misting chamber and pot culture methods gave the same diagnosis (fig. 5): i.e. RGP of all root exposure treatments was significantly lower than the control (0 min root exposure). The root growth difference between control and root exposed seedlings was substantially higher when seedlings were tested in the root misting chamber (fig. 5). In the 28-day test, however, seedlings from many of the root exposure treatments recovered, especially in the root misting chamber. The testing methods did not give the same diagnosis in the 28-day test: in pot culture, only seedlings root exposed for 10 min recovered (n.s. from control), while in the root misting chamber seedlings in all root exposure treatments recovered (all n.s. from control).

It appears that under some conditions the root misting chamber environment may be too favorable for root growth, so that weakened seedlings may recover in longer tests (28 days) and show acceptable RGP. This was true to some extent for the potting method as well. In a 14-day test, however, the two methods were equally capable of diagnosing the weakened seedlings. These results suggest that tests should be no longer than necessary to detect differences in quality; longer tests may result in greater variation among seedlings, recovery of weakened seedlings, and more roots to measure. Additional research is needed to determine all the implications of test method and test length.

This experiment also demonstrated clearly the difference in root growth rates between the root misting chamber and pot culture. For the 0 min root exposure treatment, root area index increment at 14 days was 16.2 for the root misting chamber and 12.1 in pot culture (significant at $\alpha = 0.05$); at 28 days it was 60.6 for the root misting chamber and 26.8 in pot culture (significant at $\alpha = 0.005$).

SUMMARY AND CONCLUSIONS

1. RGP is the most important measure of seedling physiological quality because it integrates an array of attributes into a single biologically meaningful measure - the ability to grow new roots. However, physiological grading is still not practical because RGP testing is not immediate like morphological measurements
2. RGP testing in pot culture, hydroponic culture, and aeroponic culture (root misting chamber)

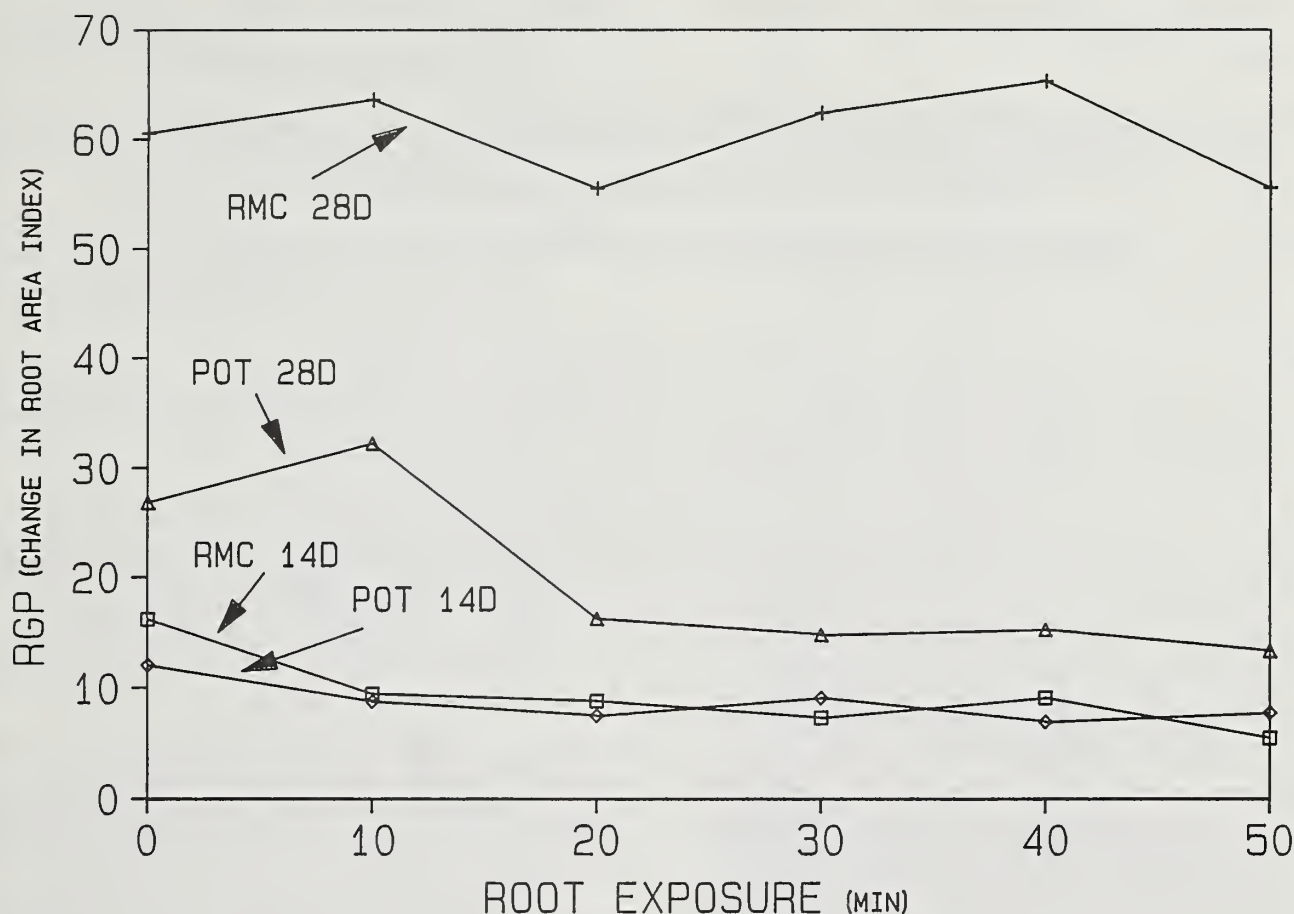


Figure 5. Root growth potential, measured as change in root area index, of 2+0 jack pine seedlings grown in aeroponic and pot culture for 14 and 28 days.

gives similar root growth patterns. New root growth was observed first in hydroponic and aeroponic culture. The three methods require approximately the same investment in equipment when maintenance of uniform root temperature is taken into account.

3. For smaller numbers of seedlings, it appears that the simplest and least expensive method of quantifying root growth is to count the number of new roots longer than a minimum length. This approach is based on a strong relation between root number and root length. The relation would be expected to weaken with longer test periods (some roots grow very long), but should still be satisfactory. Measurement of root area index increment is the easiest and fastest method of quantifying new root growth, and is well correlated with root number and length, but the equipment cost makes it more suitable for large operations.
4. Test method and test length may affect test results. Seedlings weakened from root

exposure treatments were found to recover in 28-day aeroponic tests, and to some extent in pot culture. However, both methods accurately diagnosed differences in seedling vigor in 14-day tests.

5. Root temperature, light intensity, seedling size, test method, test length, species, and seed source/family within species have all been reported to affect RGP. If a series of RGP tests will be run and the results compared, it is advisable to run preliminary screening tests before a set of testing conditions is established. The "best" testing method and conditions are those that meet specific needs and objectives, and can distinguish differences in physiological quality in the least amount of time.

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Comparison of Time and Method of Mist Chamber Measurement of Root Growth Potential¹

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Abstract.--Container-grown ponderosa pine, Douglas-fir, and Engelmann spruce seedlings were cold acclimated and deacclimated in growth chambers over 19 weeks. Weekly whole-plant freeze tests and 7- and 14-day root growth potential (RGP) tests indicated 7-day RGP results were misleading during cold acclimation and that the 14-day test period was preferable. During cold deacclimation, both RGP test periods were suitable. Quantification of RGP as total length and total number of new roots per seedling were nearly equally informative from budset to bud break, independent of the length of the RGP test.

INTRODUCTION

Root growth potential (RGP) is the ability of a tree seedling to initiate and elongate new roots when placed into an environment favorable for root growth (Ritchie 1985). It is a measure of seedling physiological quality and vigor. To become established in the field after outplanting, seedlings must be able to utilize new soil reserves of water and nutrients as those reserves in immediate contact with existing roots are depleted. New roots must be produced to accomplish this. Seedlings with a high capacity to produce new roots are likely to become established more rapidly and with less stress than comparable seedlings with a low RGP. For this reason, RGP measurements made prior to outplanting have been found to be positively correlated with the field survival and growth of many species of forest tree seedlings (Burdett 1979, Burdett et al. 1983, Jenkinson 1980, Ritchie and Dunlap 1980, Stone et al. 1961). Measurement of the RGP attribute is currently thought to be the most reliable predictor of field performance of the various seedling quality tests available (Ritchie 1985).

RGP is commonly measured using one of three approaches: the pot test, a hydroponic system, or an aeroponic system. In the pot test, originally

developed by Stone (Stone 1955, Stone and Jenkinson 1970, Stone and Schubert 1959), seedlings are potted, several per container, and maintained for 28 days at 20°C under a 16-hour photoperiod and as near field capacity as possible. Seedlings are washed from the medium to assess root growth. While this technique is successful, it has disadvantages (Ritchie 1985). Considerable time is required before results are available, and plant maintenance during that time is expensive. Potting and unpotting of seedlings is not only labor intensive, but requires large quantities of media, can result in root system damage, and does not permit examination of the root system prior to the end of the test period. Burdett (1979) addressed the problem of the lengthy test period by developing a 7-day test in which root growth was accelerated by increasing the day/night temperatures to 30°/25°C. The 7-day and 28-day test results are well correlated in a number of conifers (Ritchie 1985), though not in all species (Ritchie 1984).

The hydroponic system uses temperature-controlled aerated water baths made from aquariums painted black and covered with lids which support the seedlings with the roots submerged. Winjum (1963) used a 28-day test period, while others have successfully shortened the test to between 15 and 21 days (DeWald et al. 1985, Rose and Whiles 1985, Sutton 1980). Hydroponic systems eliminate the disadvantages associated with potting and unpotting of seedlings. Additionally, this technique requires 50% less bench space than the pot test, and the roots are easily measured because they remain clean and unbroken. Ritchie (1984, 1985) found that seedlings tested hydroponically produced about the same length and number of new roots as similar in concurrent pot tests. However, hydroponic culture of tree seedlings can result in steadily decreasing xylem water potential and minimal new root production

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(Rietveld 1986). An additional problem suspected with the hydroponic system is an unsuitability for the testing of container stock because of failure to adequately aerate the root balls.

The aeroponic system includes the use of mist boxes or chambers in which the seedling root systems are suspended (Day 1982, Hileman 1986). A 28-day test period has been used with *Pistacia chinensis* (Lee and Hackett 1976), but Tinus et al. (1986) have successfully shortened the test to 14 days with conifers by using a warm water mist to accelerate root growth. The aeroponic system has all the desirable characteristics of hydroponics plus some important additional advantages. Seedlings in mist chambers initiate new roots 1 week sooner than potted seedlings (Rietveld 1986) and produce greater numbers of regenerating roots than seedlings in concurrent pot tests (Lee and Hackett 1976). This permits shorter test periods. In addition, the aeroponically-created root environment maintains xylem water potentials similar to those of potted seedlings (Rietveld 1986) and is ideal for the testing of container stock (Tinus et al. 1986). The aeroponic system is rapidly becoming the method of choice for these reasons. USDA Forest Service initiated aeroponic RGP testing at all 11 of its nurseries in 1987.

The most desirable parameter of root growth is total new root surface area, because it is proportional to water and nutrient uptake ability (Newman 1966). However, root surface area is not readily measured. Thus, RGP is usually quantified as total length and/or total number of new roots per seedling (Ritchie 1984). Total new root length is directly proportional to surface area, if, as assumed, the new roots are nearly all the same diameter. If it is further assumed that most new roots are the same length when root growth is measured after a limited period of time, such as 14 or 28 days, then number of new roots will be strongly correlated to new root length, and thus to new root surface area also. Number and length of roots are the consequence of different processes, however. Number of roots per seedling is a measure of the initiation of new roots and the initiation of renewed growth of existing roots (Stone et al. 1963). Total length of new roots produced measures both initiation and elongation (Ritchie and Dunlap 1980). Root initiation and elongation are controlled by different mechanisms (Torrey 1976), and respond differently to factors such as chilling hours (Krugman and Stone 1966), soil temperature (Nambiar et al. 1979), and nutrient status (Nambiar 1980). Thus, it should not be assumed that number and length of roots will always be strongly correlated under all RGP test conditions.

Total length and number of new roots per seedling are thought to be fairly well correlated using the standard pot test (Ritchie 1985). Total number of new roots (≥ 0.5 cm in length) was correlated ($R=0.8667$) with total length of those new roots in *Pinus taeda* using a 28-day pot test with an average root temperature of 26.5°C (Larsen and Boyer 1986). When RGP was measured as total number of new roots ≥ 1.25 cm and as total length of new roots ≥ 2.5 cm with a 30-day pot test and

20°C root temperatures, the two approaches gave similar results (Krugman and Stone 1966). This type of data has led to the prevalent procedure of measuring only total number of roots per seedling because of the considerable reduction in the time required to count the roots as opposed to measuring root length (Ritchie 1985). Similar information on the correlation between length and number of roots is unavailable for the aeroponic method and shorter test periods.

A seedling quality test should, ideally, provide the highest quality information, in the shortest possible time, in the most efficient manner, and for the widest range of stock types. Toward this ideal with the RGP test, the objectives of this study were to examine the quality of information provided by 7-day vs 14-day aeroponic tests of container stock from bud set to bud break, with root growth quantified as total length of new roots per seedling vs total number of new roots per seedling. This research was performed within the context of a larger study examining the relationship between root growth potential and two other seedling quality parameters: cold hardiness and bud dormancy.

MATERIALS AND METHODS

Seedlings of ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm., Chevelon District, Apache-Sitgreaves National Forests, elev. 2,300 m), Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco, Cloudcroft District, Lincoln National Forest, elev. 2,700 m), and Engelmann spruce (*Picea engelmannii* (Parry) Engelm., Springerville District, Apache-Sitgreaves National Forests, elev. 3,000 m) were greenhouse-grown in 400-ml Roottrainer³ book containers in a peat-vermiculite mix for 9 months (October 1984 - June 24, 1985). Greenhouse temperatures ranged from 23 to 28°C daily (average 25°C) and 18 to 21°C at night (average 20°C). Daylength was extended to 22 hours with fluorescent light. Other cultural conditions were as recommended by Tinus and McDonald (1979). During the ninth month, the trees set bud and entered dormancy. The seedlings were then graded and those of uniform size were placed in Percival HL-60 growth chambers for a 4-stage, 19-week cold acclimation and deacclimation regime (table 1). Sodium and multivapor arc lights provided 43,000 lux, and watering was as needed with nutrient solution. At approximately weekly intervals, a sample of 20 seedlings per species was taken for concurrent tests of cold hardiness and root growth potential.

Whole-Plant Freeze Test

Cold hardiness was measured by a whole-plant freeze test. One book of four seedlings of each

³Trade names are used for brevity and specificity and do not imply endorsement by USDA or Colorado State University to the exclusion of other equally suitable products.

Table 1.--Cold acclimation and deacclimation conditions.

Stage	Day nos.	Dur- ation (wks)	Day temp. (°C)	Night temp. (°C)	Day length (hrs)	Nutri- ent Solu- tion
1	0-21	3	20	15	10	low N, high PK
2	22-71	7	10	3	10	low N high PK
3	72-105	5	5	-3	10	low N high PK
4	106-133	4	22	22	16	high N

species was placed in each of three styrofoam coolers with the rootballs supported and covered to a depth of 5 cm with dry vermiculite. The coolers, with the lids wired shut and fitted with thermister probes into the crowns of the seedlings, were placed in a 650-liter household chest freezer. Crown temperature was lowered rapidly from ambient to 0°C and at a rate of 3 to 5°C per hour thereafter. A baking pan filled with liquid nitrogen was placed in the freezer to reach temperatures below -25°C. The pan size and degree of foam insulation controlled the rate of temperature fall. Three temperatures, 5°C apart, were selected to bracket the expected LT₅₀ of the stem tissue. When a cooler reached a selected test temperature, it was removed from the freezer and placed in a refrigerator at 1°C to thaw overnight. The seedlings were then removed from the coolers and placed in a warm greenhouse (day 26°C, night 19°C, 22-hour day).

Extent of injury to each seedling was assessed after 7 days. The percentage of the length of the stem that was killed was estimated by examining the cambium and phloem for browning and loss of tissue integrity. Rates of increasing injury with decreasing temperature were compared across test day and species, and data with similar rates were subjectively placed into six groups. This pooling of data was necessary because 12 trees per species per test day did not provide adequate information for statistical analysis. Injury in the range of 10 to 90% was regressed against temperature for each group, and the 50% injury point (LT₅₀) was estimated by calibration methods (Graybill 1976). The range 10 to 90% was chosen because the relation between injury and temperature was primarily linear, but nonlinear above and below that range.

Root Growth Potential (RGP)

Eight additional seedlings per species were placed in an aeroponic mist box in a greenhouse (day 26°C, night 18°C, long days) to measure RGP. A mist box measuring 1.0 m wide x 2.4 m long x 0.6 m high, was constructed of 5 cm thick rigid urethane foam, and was fitted with a PVC piping, 3-nozzle system 25 cm above the floor of the box. The seedlings were inserted through holes in

strips of plywood which formed the top of the box, and were held in place with soft urethane foam plugs. The intact rootballs, suspended within the box, were exposed to 100% relative humidity at 27°C maintained by a warm-water intermittent mist. After 7 and 14 days, the total number of new white roots, ≥0.5 cm in length, that had emerged from the rootball were measured to the nearest cm and counted. Tallied roots were marked with tempera paint to prevent duplicate measurement. (The paint was subsequently removed by the mist.) Seedling height and caliper data were also taken. Measurements were made without damage to the seedlings, which were kept in the mist chamber until bud break to assess dormancy status.

RGP was expressed as total number of new roots per seedling and total length of new roots per seedling, at 7 and 14 days. The data sets for total new root length per seedling at 14 days for the three species were selected to assess the significance of possible covariates. There was no trend over time in seedling height or caliper in any of the three species. No consistent covariance existed between RGP and height, caliper, or (height x caliper²) in Engelmann spruce and ponderosa pine. Seedling height was a significant (p=.02) covariate in Douglas-fir, but the contribution of the covariate was so small (R²=.04) that it did not warrant inclusion in further data analysis. There was no consistent covariance between RGP and caliper or (height x caliper²) in Douglas-fir.

Box plots were used to flag outliers in the same three data sets (Chambers et al. 1983). Thirteen of the 360 seedlings, with RGP measurements several standard deviations from the weekly mean, were omitted after each seedling was found to be defective in some way, and therefore not properly part of the main population. Weekly means, with 95% confidence intervals, were calculated from the remaining observations for all 12 RGP data sets.

Homogeneity of variances was rejected (p≤.005) for all data sets using Bartlett's test. Welch's test was used for comparing all means within each data set because the data were not suitable for transformation. All hypotheses of equal means were rejected (p<.0001). Pairwise comparison of means with an F-protected LSD test, approximated using heterogeneous variance t-tests, resulted in many statistically significant differences (p=.05). However, because of the heterogeneous variances, detecting differences between means was not as straight forward as applying a standard least significant difference for all pairs compared. Thus, for ease of interpretation, major differences between means, as determined by the test of non-overlapping 95% confidence intervals (Jones 1984), were established and indicated on Figures 2, 3, and 4. The test of non-overlapping 95% confidence intervals was found to be intermediate between the more conservative Dunnett's T3 test (p=.05) (Dunnett 1980) and the more liberal F-protected LSD (p=.05). More importantly, the chosen method identified significant changes in RGP which could be readily envisioned as biologically important

differences. Means with 95% confidence intervals for the 12 data sets are presented in Burr (1987).

A correlation analysis between length and number was performed for both 7- and 14-day data, on an individual seedling basis within each species, to determine how well total number of new roots per seedling might indicate total length of new roots per seedling.

RESULTS

Whole-plant Freeze Test

Cold hardiness was gained and lost in response to the four successive temperature stages (fig. 1). Seedlings of the three species did not harden during the first stage with warm temperatures and short days (day 20°C, night 15°C, 10-hour day). Stem cold hardiness, expressed as an LT_{50} , ranged from -11 to -17°C for the three species during these first 21 days. When growth chamber temperatures were lowered to 10°C day and 3°C night in the second stage, there was a lag period of variable length, depending upon the species, before cold hardening of stem tissue proceeded. There was a 1-week lag (test days 21 to 28) in ponderosa pine, a 2-week lag (test days 21 to 35) in Engelmann spruce, and a 2-week lag after the first week of the second stage (test days 28 to 42) in Douglas-fir. Cold hardiness increased after these lag periods until maximum cold hardiness was reached at the end of the third stage (day 5°C, night -3°C) on test day 105.

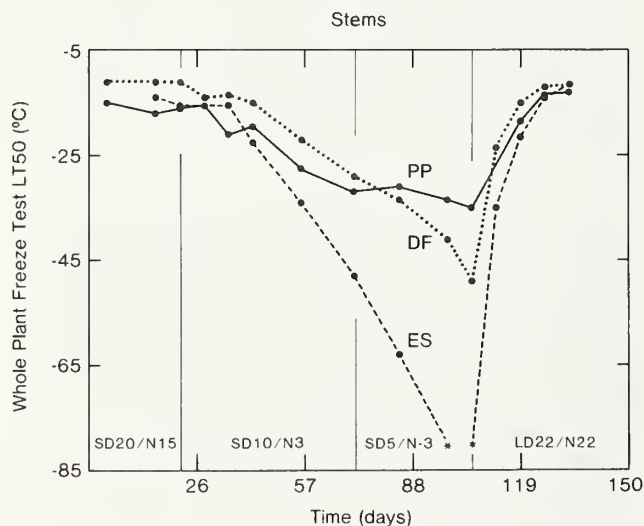


Figure 1.--Stem cold hardiness (LT_{50}) of ponderosa pine (PP), Douglas-fir (DF), and Engelmann spruce (ES) as a function of time, determined by the whole-plant freeze test. Engelmann spruce cold hardiness on test days 98 and 105 is indicated by asterisks at -80°C. On these two test days there was no injury (LT_0) to stem tissue at -75°C, the lower limit of the freezer. Growth chamber conditions are indicated across the bottom of the graph and are described in table 1.

Maximum stem cold hardiness, expressed as an LT_{50} , reached -35°C in ponderosa pine and -49°C in Douglas-fir. Engelmann spruce cold hardiness on test days 98 and 105 is indicated by asterisks at -80°C (fig. 1). On these two days there was no injury (LT_0) to stem tissue at -75°C, the lower limit of the freezer. Deacclimation began immediately in all three species upon exposure to the fourth stage conditions (day 22°C, night 22°C, 16-hour day). Cold hardiness was rapidly lost and reached minimum levels on test day 133 at the end of the 19 weeks. Stem tissue cold hardiness on test day 133 was -13°C in ponderosa pine and -11.5°C in Douglas-fir and Engelmann spruce.

Bud Dormancy

Dormancy requirements for ponderosa pine were fully met by test day 21, at the end of the first stage, and for both Douglas-fir and Engelmann spruce by test day 71, at the end of the second stage. Bud break occurred during the 18th week of the regime in Engelmann spruce, and during the 19th week in ponderosa pine and Douglas-fir.

Root Growth Potential (RGP)

The RGP patterns were similar, in a general way, for the three species, whether measured as total length or total number of new roots per seedling, after either 7 or 14 days in the mist chamber (figs. 2, 3, 4). RGP was low in the first stage when cold hardiness was at a minimum and dormancy intensity was maximum. RGP remained low for differing portions of the second stage. High, though variable, RGP levels were reached in the second and/or third stages as cold hardiness increased and chilling requirements for bud dormancy were met. Maximum RGP levels were at least 5-fold greater than minimum RGP levels. During the first week of deacclimation in the fourth stage, RGP did not decrease, although approximately 65% of maximum cold hardiness was lost. Following the first week of deacclimation, RGP declined rapidly. Both cold hardiness and RGP had returned to minimum levels at bud break.

Correlation analysis within each species indicated that total length and total number of new roots at 7 days were strongly correlated ($R=.918$ to $.933$), as were total length and total number of new roots at 14 days ($R=.889$ to $.948$) (table 2). The strength of the correlation between length and number at 7 days was similar to that at 14 days in Douglas-fir and Engelmann spruce. In ponderosa pine, the correlation between length and number was stronger at 7 days than after 14 days. The variability in total number of new roots per seedling accounted for 79.0 to 89.9% of the variability in total new root length per seedling, depending upon species and time of measurement. The patterns of the RGP means, expressed as total length and total number of new roots at each of the two measurement times, were thus very similar within each species (figs. 2, 3, 4).

In general, for the three species, changes as large or larger than a 100% increase or decrease

Table 2.--Correlation analysis between total length and total number of new roots per seedling for each species after 7 and 14 days in the mist chamber.

Species	R	R ²
Ponderosa pine		
7 days	.93330	.87105
14 days	.88901	.79034
Douglas-fir		
7 days	.92333	.85255
14 days	.94828	.89924
Engelmann spruce		
7 days	.91811	.84293
14 days	.90630	.82138

(e.g. doubling) in RGP over time were significantly different, independent of time or method of measurement. Changes in number or length of roots during the 19-week regime were not statistically significant on the same test date when measured at 7 and 14 days. When ponderosa pine RGP was measured as total new root length per seedling (fig. 2A), the first significant increase in RGP during cold acclimation occurred on test day 42 when measured at 14 days, and on test day 56 when measured at 7 days. The decrease in RGP during the third stage was not significantly different from the peak on test day 71 when measured at either time. However, the low RGP levels in the third stage were not significantly different from the earlier low levels, such as between test days 14 and 28. RGP increased on test day 112, after 1 week of deacclimation, when measured at both times, but the increase was significant only at 7 days. RGP then returned to the original low levels. When ponderosa pine RGP was measured as total number of new roots per seedling (fig. 2B), the first significant increase in RGP during cold acclimation also occurred on test day 42 when measured at 14 days, and on test day 56 when measured at 7 days. The decrease in RGP during the third stage was significantly lower than the peak on test day 71 but also significantly greater than the earlier lowest (a) levels, when measured at both 7 and 14 days. The increase in RGP during the first week of deacclimation was significant only when measured at 7 days. RGP then returned to the original low levels.

In Douglas-fir, when RGP was measured as total length or number of new roots per seedling (figs. 3A, 3B), the first significant increase in RGP during cold acclimation occurred on test day 42 when measured at 14 days, and on test day 71 when measured at 7 days. A second significant increase occurred in both the 7- and 14-day measurements by test day 84. This was followed by a significant decrease in RGP on test day 98, when measured at 7 days, which was not significantly different from the earlier lowest (a) levels. The pattern was not the same at 14 days. The changes in RGP during the first week of

deacclimation were not significant at either measurement time, and by the end of the fourth stage, RGP had returned to the earlier lowest levels.

When Engelmann spruce RGP was measured as total length or number of new roots per seedling (figs. 4A, 4B), the first significant increase during cold acclimation occurred on test day 42 when measured at 14 days, but did not occur until test day 84 when measured at 7 days. RGP fluctuated from test day 42 to the end of the third stage, on test day 105, when measured at 14 days, though none of the changes were

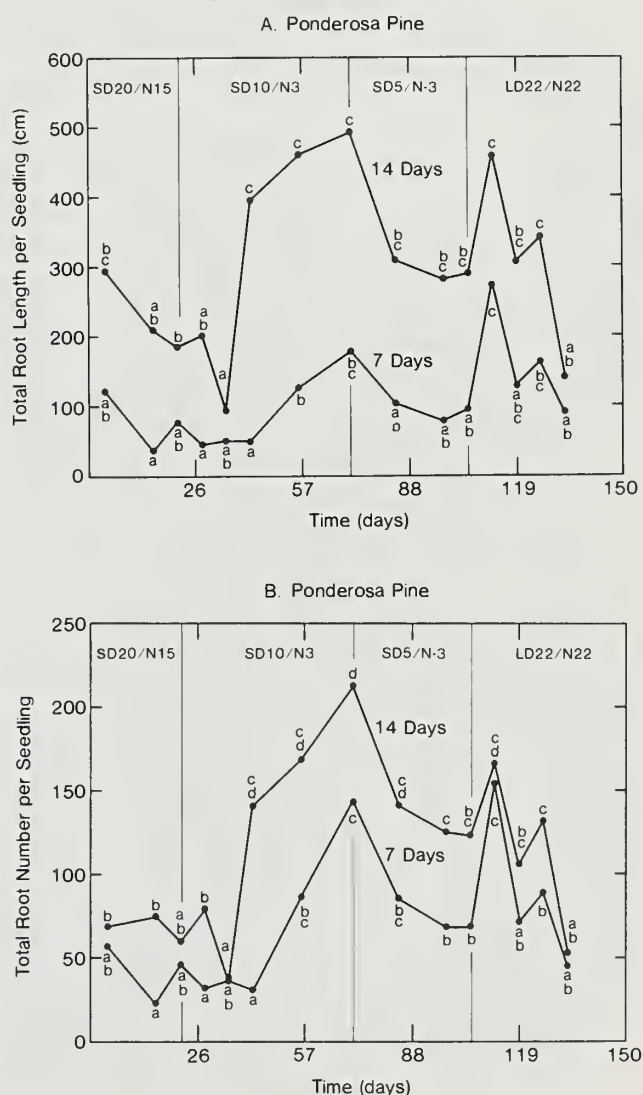


Figure 2.--Ponderosa pine root growth potential expressed as (A) total length of new roots per seedling and (B) total number of new roots per seedling measured after 7 or 14 days in a mist chamber, as a function of time. Within each curve (7 days and 14 days), means with the same letter are not significantly different. Growth chamber conditions are indicated across the top of the graphs and are described in table 1.

statistically significant. There was also no further significant change in RGP during the third stage when measured at 7 days. None of the changes in RGP during the first week of deacclimation were significant when measured after either 7 or 14 days. RGP had returned to fairly low levels at the end of the fourth stage.

Ponderosa pine data were normalized to test day 71, and Douglas-fir and Engelmann spruce data to test day 84, to illustrate the differences and similarities in the patterns of the 7- and 14-day

measurements (figs. 5, 6, 7). The normalized ponderosa pine data (fig. 5) made more apparent the 2-week delay in detecting the increase in RGP during cold acclimation when RGP was measured after 7 days. Measurement of total number of new roots per seedling at 14 days best differentiated between the low RGP levels of the third stage and of the first two stages. The increase in RGP during the first week of deacclimation was readily detected when measurements were made after 7 days.

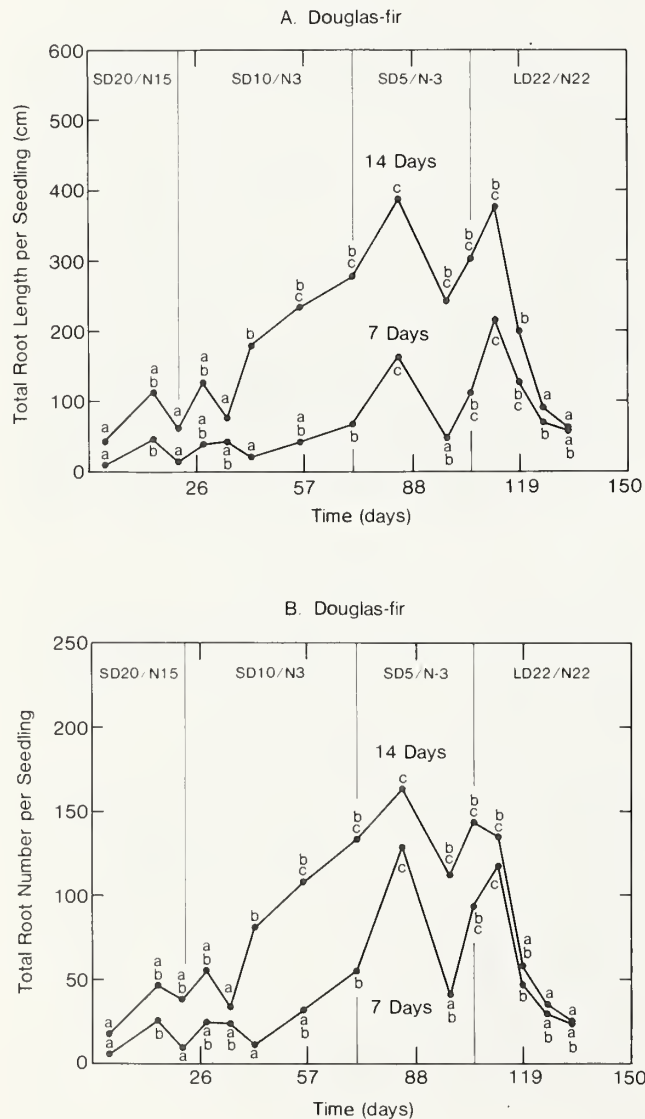


Figure 3.--Douglas-fir root growth potential expressed as (A) total length of new roots per seedling and (B) total number of new roots per seedling measured after 7 or 14 days in a mist chamber, as a function of time. Within each curve (7 days and 14 days), means with the same letter are not significantly different. Growth chamber conditions are indicated across the top of the graphs and are described in table 1.

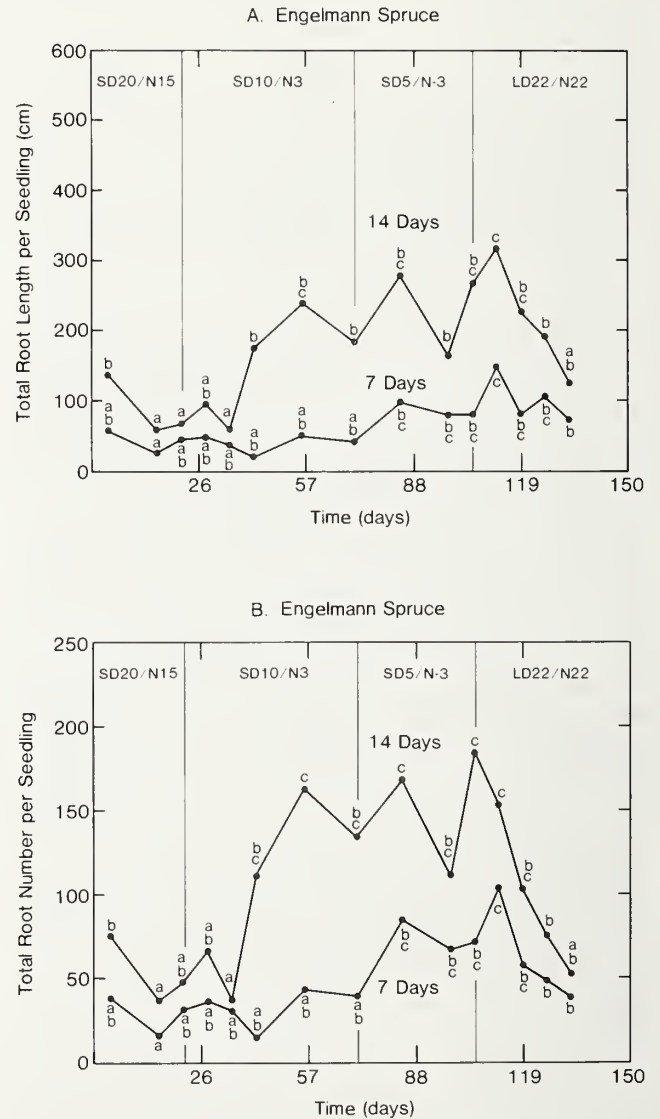


Figure 4.--Engelmann spruce root growth potential expressed as (A) total length of new roots per seedling and (B) total number of new roots per seedling measured after 7 or 14 days in a mist chamber, as a function of time. Within each curve (7 days and 14 days), means with the same letter are not significantly different. Growth chamber conditions are indicated across the top of the graphs and are described in table 1.

The normalized Douglas-fir RGP data (fig. 6) made more apparent the 4-week delay in detecting the increase in RGP during cold acclimation when measured at 7 days. Also apparent was the inability to distinguish the low RGP on test day 98 from the RGP prior to test day 42, when measured at 7 days. When measured at 14 days, the decline on test day 98 indicated a fluctuation during a period of high RGP, rather than a sudden loss of RGP. During the first week of deacclimation, 7-day measurements suggested an increase in RGP more strongly than 14-day measurements.

Normalized Engelmann spruce RGP data (fig. 7) indicated that detection of a significant increase in RGP above the low levels prior to cold acclimation in the second stage required an additional 5 to 6 weeks when measured at 7 days. During the first week of deacclimation, 7-day measurements suggested an increase in RGP, while 14-day measurements indicated no change.

DISCUSSIONS AND CONCLUSIONS

The RGP patterns of the three species (figs. 2, 3, 4) were a function of seedling response to simulated seasonal environmental changes created in growth chambers. Nevertheless, these patterns were quite representative of RGP patterns reported in the literature for nursery-grown bareroot seedlings lifted at regular intervals from bud set to bud break (Jenkinson 1980, Ritchie and Dunlap 1980, Stone et al. 1962).

RGP's measured as total number and as total length of new roots per seedling were strongly correlated in all three species, whether measured after 7 or 14 days in the mist chamber (table 2). Number of roots was a good predictor of length, indicating that changes over time in total new root length were mainly the result of changes in the number of roots elongating rather than changes in the elongation rate of the individual roots. Rietveld (1986) found that total number ($R^2=.88$) and total length ($R^2=.90$) of new roots were strongly correlated to a root area index, using a 17-day aeroponic test. Thus, not only were number and length of new roots well correlated, but both were also good estimators of new root surface area, the parameter of primary interest. Since length and number were nearly equally informative under the test conditions used here, measuring total number of new roots is recommended because it required only 25% of the time necessary to measure total new root length. More information can thus be gained per unit of time spent in data collection by measuring only the number of new roots on a 4-fold larger sample of seedlings than by also measuring total new root length on a 75% smaller sample of seedlings. For example, using the test of non-overlapping 95% confidence intervals, a doubling of the sample size from 8 to 16 seedlings would reduce the size of the confidence interval by 35%. Since a change in RGP of approximately 100% was required to be significantly different with a sample size of 8, a 65% increase or decrease would be significantly different with a sample size of 16. A 4-fold

increase in sample size from 8 to 32 would reduce the size of the confidence interval by 56% and a 44% increase or decrease in RGP would be significantly different.

A significant increase in RGP during cold acclimation was detected 2 to 6 weeks earlier in the three species when RGP was measured after 14 days, rather than after 7 days, regardless of whether root number or length was measured. The inability to detect the increase when measured at 7 days was apparently the result of low growth

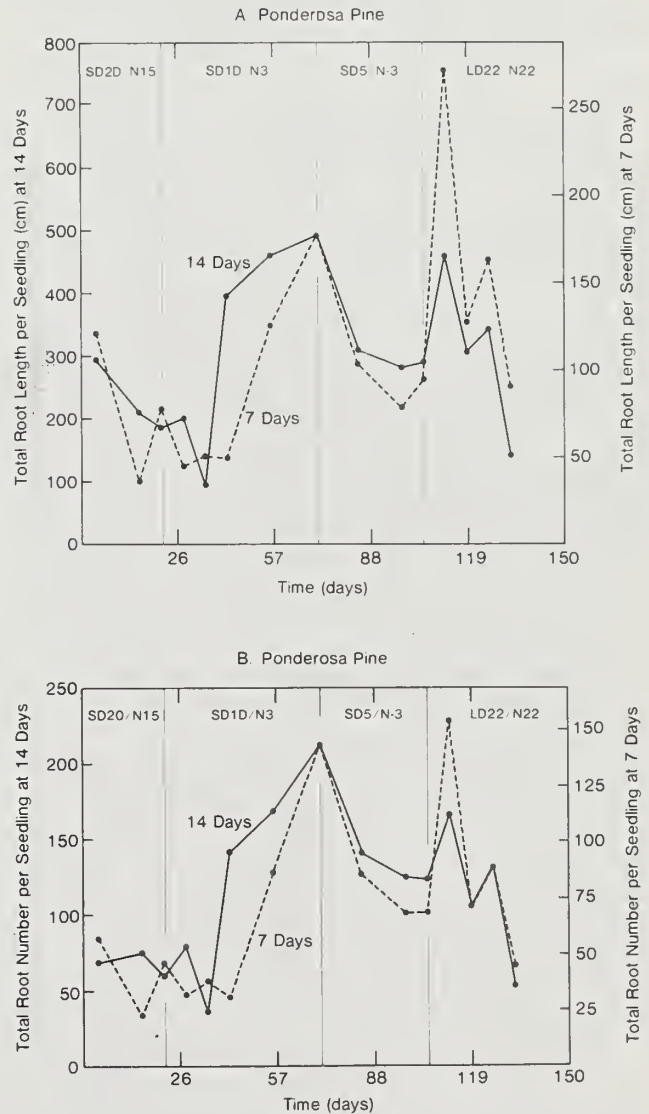


Figure 5.--Ponderosa pine root growth potential expressed as (A) total length of new roots per seedling and (B) total number of new roots per seedling measured after 7 to 14 days in a mist chamber, as a function of time. The 7-day Y-axis scales have been adjusted such that the 7- and 14-day data converge at test day 71. Growth chamber conditions are indicated across the top of the graphs and are described in table 1.

levels during the first 7 days in the mist chamber combined with high levels of growth during the second 7 days (figs. 2, 3, 4). A second disadvantage of 7-day measurement of RGP during the period of cold acclimation was the inability to distinguish between fluctuations in high RGP levels and the low RGP levels prior to the start of cold acclimation. This was particularly true in Douglas-fir (fig. 3) and also in ponderosa pine (fig. 2A). Additionally, all first significant increases in RGP, when measured after 14 days in the mist chamber, occurred on test day 42, whether expressed as total number or total length of new roots. The increase in RGP between test days 35 and 42 corresponded well with the onset of steady, rapid increases in cold hardiness (fig. 1). It marked the end of the plateau period at the

beginning of the second stage, during which there was a lag in the development of cold hardiness as well as RGP. No such relationship was apparent between cold hardiness and RGP measured at 7 days. Measurement of RGP after 7 days was not as informative as measurement at 14 days during the period of cold acclimation for these reasons. A 7-day test of RGP prior to cold deacclimation, whether as a routine test of seedling quality or over a period of time to determine lifting windows, could be very misleading.

However, measurement of RGP after 7 days may be a better indicator of the onset of deacclimation than 14-day measurement, especially in ponderosa pine (fig. 5). For example, RGP consistently increased during the first week of

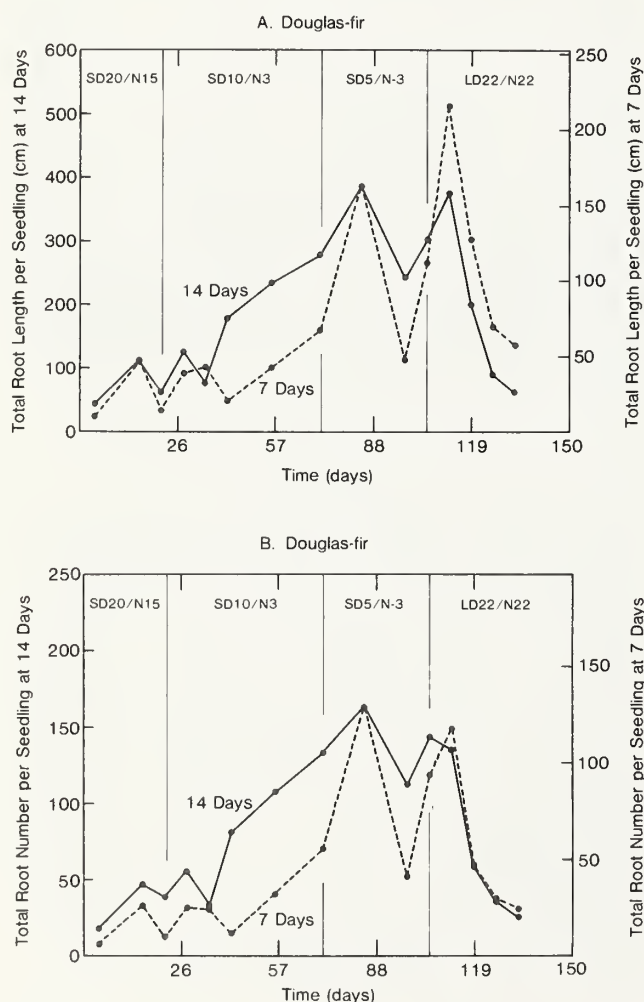


Figure 6.--Douglas-fir root growth potential expressed as (A) total length of new roots per seedling and (B) total amount of new roots per seedling measured after 7 or 14 days in a mist chamber, as a function of time. The 7-day Y-axis scales have been adjusted such that the 7- and 14-day data converge at test day 84. Growth chamber conditions are indicated across the top of the graphs and are described in table 1.

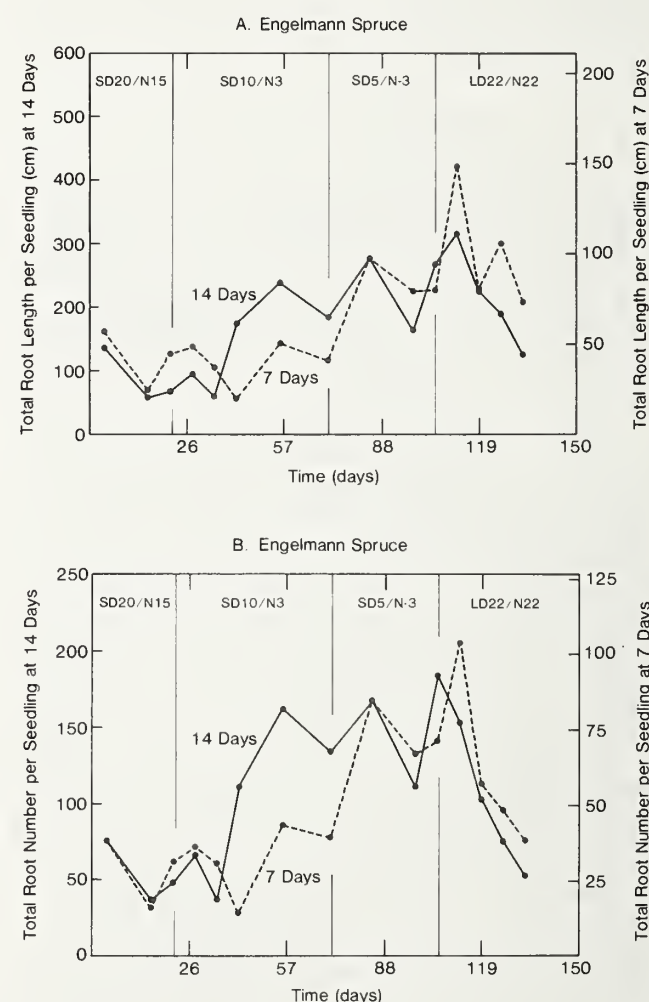


Figure 7.--Engelmann spruce root growth potential expressed as (A) total length of new roots per seedling and (B) total number of new roots per seedling measured after 7 or 14 days in a mist chamber, as a function of time. The 7-day Y-axis scales have been adjusted such that the 7- and 14-day data converge at test day 84. Growth chamber conditions are indicated across the top of the graphs and are described in table 1.

deacclimation when measured after 7 days. Though the increase was significant only in ponderosa pine (fig. 2), the normalized data (figs. 5, 6, 7) indicated that the relative magnitude of the increase was greater at 7 days than at 14 days in all instances. RGP measurement at 14 days during the first week of deacclimation led to the conclusion that no change occurred. The rapid decline in RGP after the first week of deacclimation was as clearly indicated in the 7-day measurements as in the 14-day measurements (figs. 5, 6, 7). This was true largely because the majority of the root growth, especially increases in number of roots, occurred during the first 7 days in the mist chamber. RGP measurements at 7 days are thus recommended if the data are to be used to monitor the rapid loss of stock quality with approaching bud break.

In summary, total length and total number of new roots per seedling were nearly equally informative with container stock under the mist chamber conditions described. Use of number of roots with relatively larger sample sizes is recommended as most efficient and informative. RGP tests of 7 and 14 days in duration yielded different information. On the basis of accuracy and quantity of information provided, the 14-day test is recommended during cold acclimation and the 7-day test is suggested for use during cold deacclimation.

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Effects of Lift Date, Storage, and Family on Early Survival and Root Growth Potential of Shortleaf Pine¹

S. W. Hallgren and C. G. Tauer²

Abstract.--High survival and RGP can be expected for seedlings planted from December through February even when a severe spring drought occurs. Seedling performance is only slightly reduced by storage, is positively related to number of primary lateral roots, negatively related to presence of secondary needles, and not related to the presence of a terminal bud.

INTRODUCTION

Shortleaf pine (*Pinus echinata* Mill.) is the most widespread of the southern pines. It is an important timber species, and is widely planted by the U.S. Forest Service and private industry. Current nursery practices and regeneration techniques that work well for loblolly pine are apparently inappropriate for shortleaf pine which shows very poor survival in plantations in the Ozark and Ouachita Mountains. Contributing to these poor results is the lack of specific information about artificial regeneration of shortleaf pine (Barnett et al. 1986).

Previous research has led to the recommendation that southern pine seedling quality be assessed by grading seedlings for planting. Results vary somewhat, but in general best performance can be expected from seedlings that are large and have an appropriate root/shoot ratio, that have a woody stem, secondary needles and a terminal bud (Wakely 1954, Phares et al. 1960, Grigsby 1975, Barnett 1984, Barnett et al. 1985). Shortleaf pine seedlings grown in southwest Arkansas showed high field survival when lifted and planted immediately during December through February. Only seedlings lifted in December retained high survival rates after cold storage for 30 days (Venator 1985).

The capacity of a seedling to rapidly produce new roots when transplanted into the field is critical for survival and growth. A frequently used measure of this capacity is root growth potential (RGP) which is considered a valuable tool for assessing seedling quality (Ritchie and Dunlap 1980). RGP can be measured by growing seedlings in a controlled environment for 4 weeks and counting the number of new roots greater than 1 cm long. Factors known to affect RGP are genotype, nursery environment, lifting dates, and storage (Ritchie and Dunlap 1980, Jenkinson and Nelson 1978, Carlson 1985), but very little is known about RGP in shortleaf pine.

This study was undertaken to develop improved techniques for artificial regeneration of shortleaf pine. Since there is considerable interest in managing seedlings by family we decided to evaluate the genetic variability in effects of lift date and storage on survival and growth. In order to better understand treatment response, seedlings were also measured for size, number of primary lateral roots, root growth potential and presence of secondary needles and a terminal bud.

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MATERIALS AND METHODS

Shortleaf pine seedlings of 12 open-pollinated families from Oklahoma and Arkansas were grown for one season under operational procedures at the Weyerhaeuser Company Nursery at Fort Towson, Oklahoma. Seedlings were grown in 3 replicates in a randomized complete block design. They were operationally undercut at a depth of 15 cm in November 1986.

Starting December 1, 1986, one fifth of the seedlings in each replicate were hand-lifted every 28 days for 5 lifts until March 23, 1987 (Table 1).

Table 1.--Schedule of Lift and Plant Activities

<u>Lift</u>	<u>Not Stored</u>	<u>Plant Stored</u>
Dec. 1	Dec. 2	
Dec. 29	Dec. 30	Dec. 30
Jan. 26	Jan. 27	Jan. 27
Feb. 23	Feb. 24	Feb. 24
Mar. 23	Mar. 24	Mar. 24
		Apr. 21

Following each lift seedlings were graded according to operational standards and divided into two equal groups, one for immediate testing and one to be stored for 28 days and then tested. Each group was divided a second time, 80 seedlings per family going to the field planting and 24 to the RGP test. The integrity of nursery replicates was maintained throughout the study.

The field test was planted at the Kiamichi Forest Research Station near Idabel, Oklahoma. Seedlings were planted one day after lifting or upon removal from 28 days of storage. The experimental design was a 12 x 5 x 2 (family x lift date x storage) factorial with 10 replicates laid out in randomized complete block design. Each treatment combination was represented by an 8-tree row plot in each replicate. A total of 9600 trees were planted at a spacing of 0.5 m and the entire experiment was surrounded by a border row of similar shortleaf pine seedlings. Immediately after the last planting, all the seedlings were measured for survival, diameter and height.

Weeds were controlled by herbicides and manual methods. No irrigation was applied. Temperature and precipitation were monitored at a weather station on the center. Early survival was counted on June 22, 1987. The experiment will be monitored for survival and growth for two years.

Seedlings for the RGP test were kept in cold storage until the test began 3 days after lifting or the end of the cold storage treatment. Prior to commencement of the RGP test seedlings were measured for height, diameter, number of primary lateral roots, root volume and presence of secondary needles and a terminal bud.

Three seedlings of a family were planted into 1 l milk carton pots filled with a 1:1 peat-vermiculite mixture (on the first test date, 2 l cartons were used). The pots were arranged in a randomized complete block design with 8 replicates. The test was conducted in a controlled environment chamber set for a 16 hour photoperiod and a 25° C day/15° C night. After 28 days the seedlings were removed from the chamber and placed in cold storage until the roots could be washed and the new root tips longer than 1 cm counted. RGP measurement was complete within 2 to 3 days.

The data were subjected to analysis of variance to determine the significance of family, lift date and storage on RGP and seedling survival. Phenotypic correlations between survival and the various seedling traits were calculated.

RESULTS AND DISCUSSION

Lift date, storage and family all showed a significant effect ($P < 0.05$) on survival and RGP of shortleaf pine (Table 2).

Table 2.--Analysis of Variance Results

<u>Probability > F</u>			
<u>Source</u>	<u>DF</u>	<u>Survival</u>	<u>RGP</u>
Date (D)	4	<0.0001	<0.0001
Storage (S)	1	<0.0001	0.0465
Family (F)	11	<0.0001	<0.0001
D x S	4	<0.0001	<0.0001
D x F	44	0.2765	<0.0001
S x F	11	0.7704	0.4405
D x S x F	44	0.0323	0.2512
Error	1071/833		

A significant interaction of lift date with storage suggested that seedling performance after storage is dependent in part on lifting date. The lack of an interaction between family and lift date and family and storage treatment for survival indicates that in general the families respond in a similar manner to lift date and storage. However, a significant three-way interaction between lift date, family and storage treatment suggests the survival response is complex. In general, the families showed a dissimilar RGP response to different lift dates but a similar RGP response to storage treatment.

These results correspond well with previous work in pines that has shown lift date to affect survival and RGP (Jenkinson 1975, Jenkinson and Nelson 1978). Lift date is also known to determine the response of seedlings to storage (Stone and Jenkinson 1971, Venator 1985). The pattern of changes in RGP and survival with time of lift as well as the magnitude of RGP at a given date have been shown to be under strong genetic control (Jenkinson 1975, Nambiar 1982, Carlson 1985 and 1986).

Overall, survival was high, over 90 percent, for seedlings planted from early December to late February whether they were stored or not (Figure 1). Survival fell after February and the late March planting showed survival of 80 and 85 percent for freshly lifted and stored seedlings. Only stored seedlings were planted in late April and survival was poor, less than 50 percent.

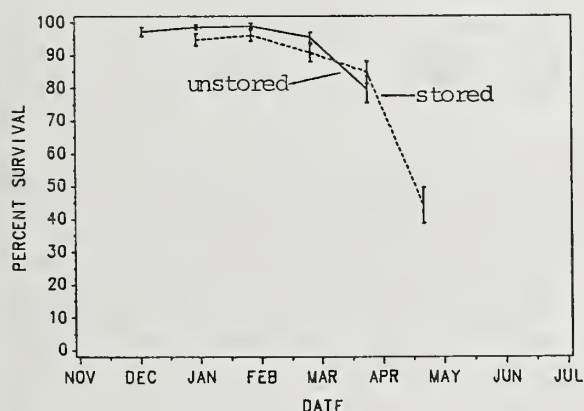


Figure 1. Effect of lift date and storage on June 22 survival of shortleaf pine seedlings by planting date. Points represent values averaged across 12 families and bars represent plus and minus the standard error of the mean.

The late season drop in survival can be at least partially explained by the weather at the planting site. Temperatures were mild and precipitation adequate from November 1986 through March 1987. The weekly maximum temperatures never exceeded 30°C and monthly rainfall ranged from 45 mm in December to 164 mm in March. April and early May were much hotter and drier with weekly maximum temperatures constantly above 33°C and rainfall of only 9 mm from March 30 until May 15. Temperatures remained high and precipitation returned to higher levels for the last 2 weeks of May (154 mm) and the first 3 weeks of June (40 mm).

Survival for a specific planting date was generally reduced only 5 percent by storage (Figure 1). Seedlings lifted on a given date showed a reduction in survival due to storage of only 2 percent in December, 8 to 10 percent in January and February and 36 percent in March. The March lifted seedlings planted in April showed poor survival partly due to the spring drought.

RGP followed a seasonal pattern somewhat similar to that for survival, showing high values of 80 to 110 new roots for seedlings lifted in December, stored and unstored, and in January, unstored (Figure 2). RGP fell to 50 to 75 new roots for stored seedlings lifted in January and all seedlings lifted after January whether stored or unstored. The stored seedlings tested in April showed a higher RGP than seedlings tested in March and yet they showed much lower survival in

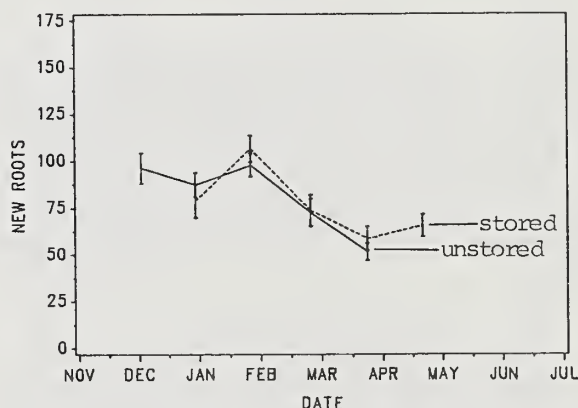


Figure 2. Effect of lift date and storage on root growth potential of shortleaf pine seedlings by date tested. Points represent values averaged across 12 families and bars represent plus and minus the standard error of the mean.

the field. Apparently the higher RGP did not prevent severe mortality for seedlings planted in the middle of the spring drought. It is worth noting that in general RGP declined for seedlings lifted in February and later at the same time that risk of mortality from drought and high temperature was increasing. The effects of storage on RGP were generally small and inconsistent from one lift date to the next.

Comparison of survival across all dates for families showing the highest (Family 5) and lowest (Family 6) survival reveals small differences for unstored

seedlings, usually less than 10 percent, and much larger differences for stored seedlings, usually 20 percent or greater (Figure 3). These families showed similar seasonal changes in survival and maintained their respective ranks regardless of storage treatment.

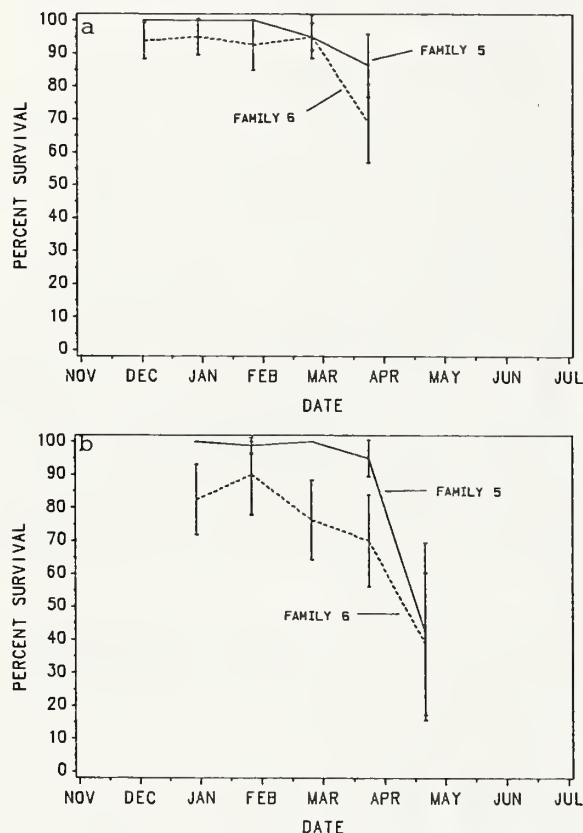


Figure 3. Effect of lift date and storage on June 22 survival of shortleaf pine families showing the highest (Family 5) and lowest (Family 6) overall survival. Data are plotted by date planted for unstored (a) and stored (b) seedlings. Bars represent plus and minus the standard error of the mean.

RGP showed a good relationship to field survival, as high survival for Family 5 was associated with high RGP and low survival of Family 6 was associated with low RGP across all dates regardless of storage treatment (Figure 4). Unstored seedlings showed a peak RGP in early December for Family 5 and late January for Family 6. Stored seedlings showed a peak RGP for both families in late January.

Survival was significantly correlated to RGP and number of primary lateral roots

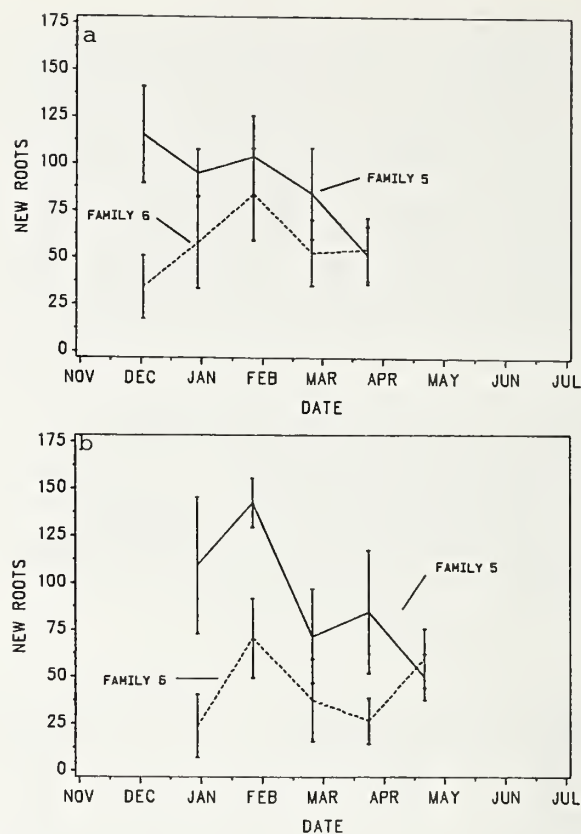


Figure 4. Effect of lift date and storage on root growth potential of shortleaf pine families showing highest (Family 5) and lowest (Family 6) overall survival. Data are plotted by date tested for unstored (a) and stored (b) seedlings. Bars represent plus and minus the standard error of the mean.

(Table 3). Previous research has often shown a close relationship between RGP and survival (Ritchie and Dunlap 1980, Nambiar et al. 1982, Larsen et al. 1986). Other root characteristics such as root weight and shoot/root ratio may be correlated with survival (Larsen et al. 1986), and the importance of primary laterals in development of RGP has been noted (Nambiar et al. 1982). The current study clearly shows the close relation between number of primary laterals and survival. In fact, it was a better predictor of survival than RGP. Number of primary laterals is easier to measure than RGP and should be given consideration as a measure of seedling quality.

Survival showed no correlation with root volume, diameter and height (Table 3). We observed that root volume appeared to be largely determined by the tap root size which was reflected in seedling diameter, hence the close relation between

Table 3.--Phenotypic Correlations for Survival and Various Seedling Traits

	RGP	ROOT	ROOT VOL.	DIA	HGT	BUD	SECONDARY NEEDLES
SURVIVAL	.657*	.709*	.109	-.173	-.093	-.263	-.661*
RGP		.900**	.527	.216	.126	-.268	-.299
ROOT			.624*	.290	.223	-.140	-.278
ROOT VOL.				.842**	.327	.353	.384
DIA.					.614*	.600*	.620*
HEIGHT						.384	.246
BUD							.707**

* Significant at 5% level

**Significant at 1% level

root volume and diameter. Apparently, the number of primary lateral roots is more important in determining survival than tap root size.

Surprising was the fact that survival was not related to the presence of a bud and was negatively related to the presence of secondary needles. The presence of both a terminal bud and secondary needles has been suggested as important to seedling quality (Wakely 1954, Barnett et al. 1986). The data from this study indicates that this recommendation should be reevaluated, at least for shortleaf pine. Very little attention has been paid to this species and it appears that regeneration techniques developed for other southern pines are not well suited to it.

RGP was, not surprisingly, strongly correlated to number of primary lateral roots. This again reinforces the suggestion that number of primary laterals be considered as a measure of seedling quality. RGP was not related to any of the other seedling traits.

CONCLUSIONS

Early results show survival is high for seedlings lifted from early December through the end of February and planted without storage. Seedlings lifted in December and January can be stored for 28 days with only a slight reduction in survival. Seedlings planted in March and April are subject to greater mortality. High RGP and number of primary lateral

roots are associated with high survival. The presence of a terminal bud shows no relation to survival, and the presence of secondary needles appears to be negatively related to survival. Family differences in performance indicate a significant opportunity to improve regeneration techniques through management of seedlings by family.

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Fall Lifting: Its Effects on Dormancy Intensity of Ponderosa Pine Seedlings — A Preliminary Investigation¹

Steven K. Omi and Ursula K. Schuch²

Abstract.—Initial assessment of the feasibility of fall lifting ponderosa pine seedlings at Bend Pine Nursery, Oregon, involved calculating fall chilling hours and monitoring release of seedlings from dormancy. Seedlings lifted earliest failed to break bud, whereas budbreak was accelerated for trees lifted later in the fall. Results suggest that chilling was required to release seedlings from dormancy.

INTRODUCTION

Three basic lifting practices are available for use in high elevation or latitude nurseries: (Option 1) fall lift and plant, (Option 2) late winter or spring lift and plant, and (Option 3) fall lift, overwinter storage, and plant. Disadvantages of Option 1 include risks that early fall snows or drought will terminate the planting operation (Tung et al. 1986) and that stock will be lifted before it is physiologically ready (Ritchie et al. 1985). Fall lifting date is critical because of the potential to upset natural phases of dormancy and release of seedlings from dormancy.

A disadvantage of Option 2, the most common practice in the Northwest, is that nursery soils may remain frozen in the spring when sites are ready for planting. In addition, seedlings left in the ground during winter months may be exposed to desiccating conditions and may be sensitive to physiological stress at the end of the safe lifting window (Ritchie and Dunlap 1980, Ritchie et al. 1985).

Disadvantages of Option 3 include that of Option 1 regarding fall lifting date. Further—

more, storage can be unsuccessful if seedlings are lifted prior to the period of deep dormancy, when buds are not responsive to chilling (Stone and Schubert 1959, Ritchie and Dunlap 1980). Seedlings which are not at their fully dormant stage have higher respiration rates (Hocking and Ward 1972, Navratil 1973) and may deplete their reserves faster during storage than do fully dormant seedlings. Use of Option 3 has been discouraged in the past (Hocking and Nyland 1971, Hermann et al. 1972, Navratil 1973), based on data primarily derived from research on mid- or low-elevation conifer species (Tung et al. 1986). Recent studies, however, indicate that fall lifting and long-term cold storage of high elevation or latitude stock are feasible (Ritchie et al. 1985, Tung et al. 1986).

Fall lifting and overwinter storage ensure that stock is available when sites are ready for planting. This practice alleviates winter losses due to rodents, desiccating winds, or extreme temperatures (Hocking and Nyland 1971). In addition, it allows greater flexibility in the workload and makes nursery areas available for early cultivation (Hocking and Ward 1972, Mullin and Bunting 1972, Hinesley 1982). Low temperature storage of seedlings also can play a role in satisfying chilling requirements (van den Driessche 1977, Ritchie et al. 1985). The relationship among lifting date, chilling hours, and dormancy intensity for ponderosa pine is not well known.

Bend Pine Nursery (Bend, Oreg.) is located at an elevation of 3700 ft (1100 m), where soils can remain frozen in spring when lower elevation forest sites are ready to plant. Fall lifting has not been attempted recently at this nursery; however, the practice of fall lifting and overwinter storage is used for a variety of conifer species at three USDA Forest Service nurseries in the Northwest/Intermountain

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region--Wind River Nursery (Carson, Wash.), Lucky Peak Nursery (Boise, Idaho), and Couer d'Alene Nursery (Idaho). These nurseries are similar to Bend Pine Nursery in that their operations are subject to winter snows and frozen soils.

A preliminary trial was initiated in fall 1986 to assess the feasibility of fall lifting at Bend Pine Nursery. The objectives of the investigation were to determine (1) the dormancy status of fall-lifted trees and the preferred chilling range for release of seedlings from dormancy, and (2) the relationship between cumulative chilling hours and budbreak.

METHODS

Two-year old seedlings from three seed sources (courtesy of Warm Springs Indian Reservation in central Oregon--seedlots 38-85112 [3000 ft], 38-85110 [3500 ft], and 38-85105 [4000 ft]) were selected for study. These seed sources were chosen because seedlings could be destined for sites which are plantable prior to the average spring thaw in the nursery--a situation in which fall lifting and overwinter storage could be advantageous. Seedlings were shovel-lifted on three dates (October 22, November 5, and November 13, 1986) from four replications of each seed source. An additional lift of seedlings from seed source 3500 ft was made on February 19, 1987. Immediately after lifting, seedlings were packed in ice, transported to Corvallis, Oreg., and placed in cold dark storage (2°C) for approximately 12 h. Seedlings from each replication then were potted (10 seedlings per pot, 4 pots per seed source) in a 1:1:1:2 soil:sand:peat:pumice mixture and placed in a glasshouse with a 13-h extended photoperiod supplemented with lighting from 300-watt incandescent bulbs. Daily maximum and minimum temperatures were approximately 24°C and 12°C, respectively. Soil moisture was maintained near saturation.

Dormancy intensity was determined by scoring each seedling for terminal budbreak (separation of bud scales to reveal emerging needles) and tallying percent budbreak for each pot of 10 seedlings. Seedlings were monitored for 20 wk after each 1986 lift date; the 1987 lift was assessed for 7 wk.

Sensors at the nursery weather station took a temperature reading every 5 min and recorded hourly averages. Cumulative chilling hours were determined by summing the number of hours that the average hourly temperature was within a given range. Temperature ranges were defined as: (1) less than or equal to 5°C (41°F), (2) 0-5°C, (3) less than or equal to 10°C (50°F), and (4) 0-10°C. The starting date for accumulation of chilling hours was set arbitrarily as September 10. Chilling hours were calculated for three sensor locations from September 10, 1986 to February 19, 1987.

To quantify the relationship between chilling hours and budbreak, percent budbreak for each seed source after 20 wk was plotted against cumulative chilling hours. Examination of residual plots after fitting linear relationships, lack of fit tests, and tests for nonconstant error variance (Weisberg 1985) suggested that linear models were not appropriate for the untransformed data. An arcsine square root transformation of the budbreak proportions was found to linearize the relationship and stabilize the variance for seed sources 3000 and 4000 ft; a quadratic term was required for fitting the regression equation for seed source 3500 ft.

RESULTS

Chilling hours generally started to accumulate during September, and increased later in the fall, regardless of chilling temperature range (fig. 1). However, as indicated in

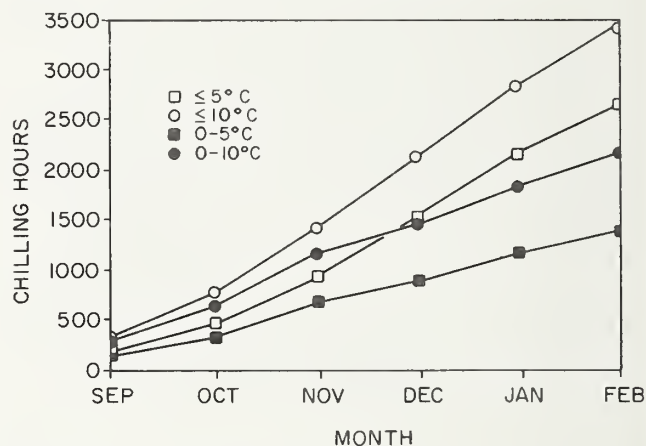


Figure 1.--Cumulative chilling hours from September 10, 1986 to February 19, 1987 at 20 cm above the surface for four temperature ranges.

figure 1, cumulative chilling hours differed, depending on the temperature range defined. For example, cumulative chilling hours in February differed nearly threefold between the temperature range less than or equal to 10°C and that from 0 to 5°C.

As expected, the later the lift date, the more chilling hours the seedlings received (table 1). Chilling hour data (temperature range less than or equal to 5°C) for the sensor 20 cm above ground surface indicated that the first three lift dates differed by over 100 h each (table 1). More than 2400 chilling hours were received by seedlings lifted February 19.

Percent budbreak was similar for all three seed sources (fig. 2). Budbreak in the glasshouse environment was virtually nonexistent for trees lifted October 22; no budbreak occurred

in seedlings from seed sources 3000 and 4000 ft. Slightly more activity (8-13 percent budbreak after 5 mo) occurred in seedlings lifted November 5, and the percentage of seedlings which flushed after 12, 16, and 20 wk increased consistently for all seed sources lifted November 13. Budbreak was especially accelerated for seedlings (seed source 3500 ft) lifted February 19 (fig. 3). These trees achieved the same amount of budbreak after 6-7 wk as the trees lifted on November 13 did after 20 wk.

In an attempt to determine a preferred chilling range for releasing ponderosa pine seedlings from dormancy, percent budbreak after 20 wk was plotted against cumulative chilling hours for the four temperature ranges studied. Similar to findings of Ritchie et al. (1985), all chilling ranges exhibited similar patterns and none was clearly advantageous. Therefore, the range less than or equal to 5°C was utilized for remaining analyses because of its practical use in tallying chilling hours in some Northwest nurseries (Ritchie et al. 1985).

The relationship between budbreak proportion after 20 wk (transformed) and cumulative chilling hours was linear for the 3000 and 4000 ft seed sources. Regression equations derived from data on these seed sources did not differ statistically ($p > .05$); therefore, data were combined to produce a single linear regression model (fig. 4, budbreak = $-1.074 + .003$ [chilling hours]). Differences in chilling hours accounted for 74 percent of the variation in budbreak for

Table 1. Chilling hours accumulated from September 10, 1986 to four 1986-1987 lifting dates at three sensor locations for four temperature ranges.

Time period	Sensor location	Chilling hours accumulated			
		Temperature ranges			
	above ground	≤5°C	0-5°C	≤10°	0-10°C
Sept 10-Oct 22	1.5 m	322	278	666	622
	20 cm	396	290	644	538
	surface	205	195	533	523
Sept 10-Nov 5	1.5 m	443	382	884	823
	20 cm	533	391	856	714
	surface	337	327	737	727
Sept 10-Nov 13	1.5 m	599	477	1065	943
	20 cm	683	472	1029	818
	surface	474	441	908	875
Sept 10-Feb 19 ¹	1.5 m	2459	1466	3336	2343
	20 cm	2478	1369	3238	2129
	surface	2551	1863	3210	2522

¹Information from 4:00 p.m. December 8 to 11:00 a.m. December 9 not available.

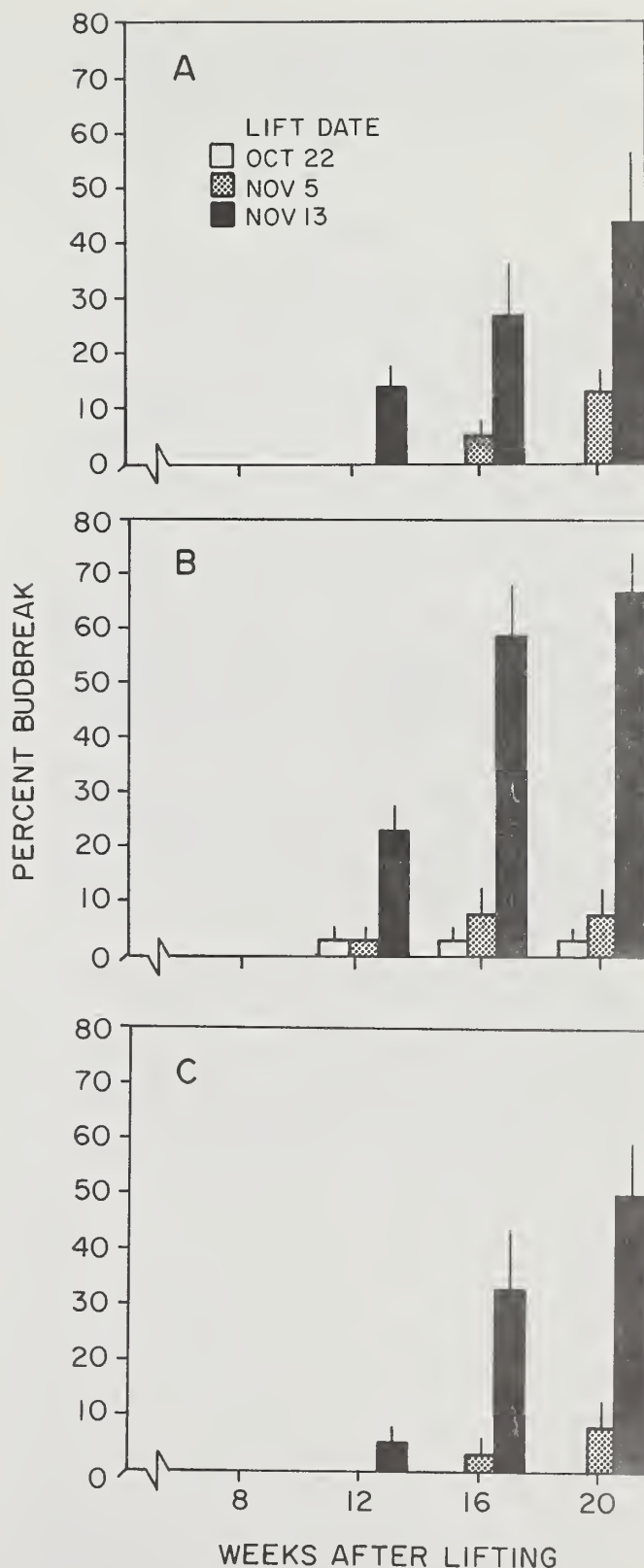


Figure 2.--Percent budbreak (\pm SE) for seedlings from seed sources (A) 3000 ft, (B) 3500 ft, and (C) 4000 ft assessed for 20 wk after three lifting dates.

these two seed sources ($n = 24$). A curvilinear relationship existed for seed source 3500 ft ($n = 12$), with a coefficient of determination equal to .85 (fig. 4, budbreak = $2.874 - .013$ [chilling hours] + $.00001$ [chilling hours]²).

DISCUSSION

The number of chilling hours required for growth to resume following dormancy has been estimated at 1200 h at 0-10°C or 1400 h below 5°C for Douglas-fir (Ritchie and Dunlap 1980). Such information for ponderosa pine is lacking. With the assumption that differences in budbreak between lifting dates were due to differences in cumulative chilling hours, the results of this trial suggest that seedlings from the tested seedlots had a chilling requirement. Seedlings in the greenhouse were never exposed to long photoperiods (e.g., 16 h), which can compensate partially for inadequate chilling (Campbell and Sugano 1975). Apparently, seedlings were in deep dormancy during the early fall lift, and may have been unable to resume growth because they needed chilling hours (Perry 1971). Thus, seedlings could have been released from dormancy with the accumulation of chilling hours (e.g., Lavender 1985).

In contrast to the findings of this trial, Tinus et al. (1986) reported no chilling requirement for ponderosa pine. They used a high elevation (7000 ft) Arizona seed source and raised seedlings in containers under greenhouse conditions.

Chilling hour data were retrieved from the weather station with only minor problems. Installed recently (June 1986) for the USDA Forest Service Reforestation Improvement Program (see Rietveld, this proceedings), the weather station immediately showed its potential use in collecting beneficial information for the nursery. Nonetheless, determination of chilling

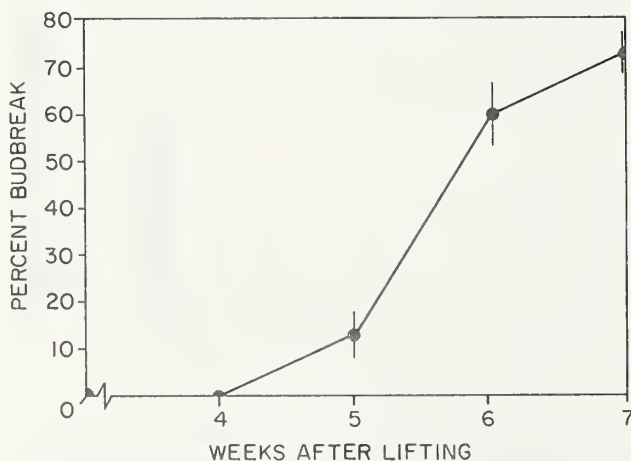


Figure 3.--Percent budbreak (\pm SE) for seedlings from seed source 3500 ft assessed for seven weeks after lifting February 19, 1987.

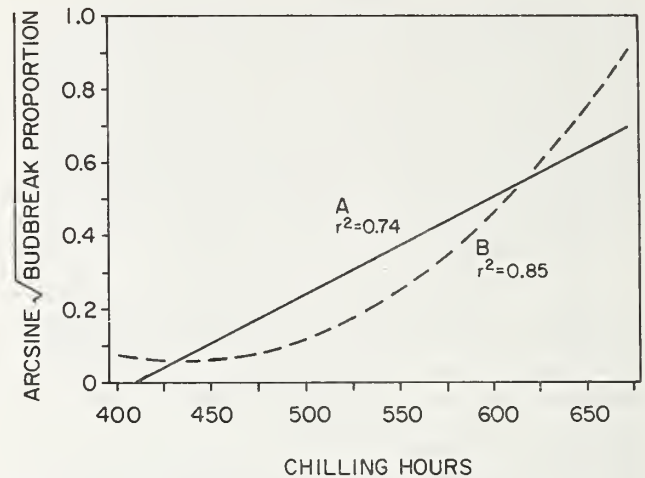


Figure 4.--Relationship between budbreak proportion (transformed) and chilling hours for seed sources (A) 3000 and 4000 ft, and (B) 3500 ft.

requirements poses numerous problems. Not all chilling temperature hours below a specified quantity are equally effective in releasing seedlings from dormancy (Ritchie et al. 1985). In addition, the chilling period may be interrupted by warm temperatures. The relationship between chilling hours and release of seedlings from dormancy under controlled environments will be more intensively studied during fall 1987. In addition, investigations of the interaction between dormancy intensity of fall-lifted trees and the ability to tolerate long-term storage, as well as of effects of fall lifting and long-term storage on seedling carbohydrates and outplanting performance, are planned for 1987.

ACKNOWLEDGEMENTS

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A Status Report on Nursery and Reforestation Projects at the Missoula Technology and Development Center¹

Ben J. Lowman²

Abstract.--This paper presents an overview of work underway in the nursery and reforestation program at the Missoula Technology and Development Center. Projects include the Seedling Counter, Seeders, Seedling Handling Equipment, Root Regeneration Chambers, a Stake Driver, an Improved Planting Auger, and Field Storage.

INTRODUCTION

The Missoula Technology and Development Center (MTDC) has a long history of development in nursery and reforestation work. Current projects at MTDC are indicative of a continued commitment to improve Forest Service reforestation and nursery programs. The status of current projects follows:

Nursery Technical Services.--Our goal in this project is to provide engineering assistance to Forest Service nurseries and to disseminate information to help nursery managers keep current with technological advances. Under this project, we maintain drawing files on nursery equipment and send them to nursery managers and others on request. In FY 1987 MTDC built 14 Root Growth Chambers and drawings were prepared based on Dr. Tinus and Dr. Reinfelt's design. In addition, electrical protection was provided for 44 weather stations associated with the Reforestation Improvement Program. Detailed construction plans for two sizes and types of Root Growth Chambers are available on request.

Seedling Counter.--Forest Service nursery managers must have an accurate and current count of their seedling crop by age and seedlot for inventory, planning, and scheduling. Our goal is to provide a fast, accurate, and inexpensive system for counting seedlings in the nurserybed. After analyzing current technology, Center engineers decided that an optical-electrical approach was the most feasible. A contract was awarded to Dr. Glenn Kranzler at Oklahoma State University to continue his work on seedling counting. Dr. Kranzler performed laboratory tests that provided information Center engineers used to design a prototype counting system. The counting system uses laser beams with linear array detectors and light emitting diodes with linear array detectors. Preliminary tests at Lucky Peak Nursery in Boise, Idaho, showed promise. Further tests and refinements of the counter will continue in 1988.

Seeders.--Uniformly spaced seed in the nurserybed helps determine the quality of stock produced. Nursery managers need a precision seeder to accomplish this. MTDC continues to monitor industry to determine the state-of-the-art in precision seeders. We are particularly interested in high speed transplanting equipment used in row crops. In 1988, Center engineers will conduct lab tests on at least two precision seeders to determine their applicability for sowing longleaf pine seed. MTDC engineers will also design, fabricate, and test an improved hand seeder for sowing small progeny seed lots.

Seedling Handling Equipment.--As the direct result of a survey of Federal nursery managers, MTDC designed, fabricated, and tested a prototype box pickup and conveyor system for moving tubs full of trees from the ground to a trailer for transporting to the packing shed. Design, fabrication, and initial testing will be completed by the end of 1987. Information and drawings of this system will be available in the spring of 1988.

Stake Driver--A three-point hitch-mounted stake driver was designed, built, and transported to Bend Pine Nursery for use in installing netting that protects seeds from birds. This stake driver was used in the spring of 1987 with excellent success. Drawings are available.

Improved Planting Auger.--The Intermountain Forest and Range Experiment Station experimented with varying the shape of planting holes to improve seedling establishment and growth. They found that cone-shaped holes appear best suited for bareroot seedlings. MTDC was asked to design and build several styles of cone-shaped augers for evaluation. Six prototype augers were built and evaluated in the Intermountain and Pacific Northwest Regions. Personnel selected a prototype design that creates a 4-inch diameter hole. Its bottom 6 inches is tapered to about 1 inch. Ten of these augers are being field tested. MTDC will refine the augers in 1988.

Field Storage.--The nursery manager must protect seedlings from injury and damage from the time they emerge until they reach their shipping destination. Nursery managers usually have the equipment, materials, and trained personnel to provide the necessary protection, but field units that take possession of the planting stock often cannot provide protection. Portable pick-up sized cold transport units are

needed. In FY 1987, center personnel contacted field units to define the requirements for such transport and storage units. One manufacturer sent a proposal for a unit using the truck 12-volt system, batteries, solar panels, and eutectic cold plates for refrigeration. The proposal has been sent to 15 field units for their comments. MTDC will analyze these comments and base further work on the results of this analysis.

Grading Pine Seedlings with Machine Vision¹

Glenn A. Kranzler and Michael P. Rigney²

A machine vision technique for grading pine seedlings at production line rates was developed. Singulated seedlings were inspected on a moving belt. Classification as acceptable or cull was based on minimum criteria for stem diameter, shoot height, and projected root area. Individual seedlings were graded in approximately 0.25 seconds. Average classification error rate was 5.7 percent.

INTRODUCTION

Hundreds of millions of tree seedlings are grown each year in commercial, federal, and state nurseries. At harvest, these bare-root seedlings are graded to remove inferior stock and improve productive potential.

Grading is typically performed manually by grasping individual seedlings from a conveyor belt and applying a number of visual quality criteria. Manual inspection tends to be labor-intensive and costly. Seedling classification is subjective and susceptible to human error. Grading into more than two classes is not feasible. Valuable production data such as seedling count and classification statistics are difficult to obtain. Disadvantages of manual grading have spurred growing interest in automated alternatives.

A seedling grading machine was commercially tested by Lawyer (1981). This mechanical system measured stem diameter, shoot height, count, and classified seedlings into three grades. However, productivity was only 1000 seedlings per hour, a rate approximately three times slower than manual grading.

A digital electronic system for measuring and recording seedling diameter, height, root area index (silhouette area), and sample number was described by Buckley et al. (1978). Potentiometric transducers and a linear 1024 element photodetector were employed. Although measurements were accurate, the apparatus was much too slow to grade large quantities of seedlings at production line rates.

Digital image processing has been successfully implemented in many industrial and agricultural inspection processes. It has demonstrated high accuracy and throughput and has permitted 100% inspection in applications which were previously not feasible

(Kranzler 1985). Machine vision inspection would appear to be an ideal tool for addressing the tree seedling grading problem.

OBJECTIVES

This study was initiated to investigate the ability of machine vision to grade bare-root pine seedlings under nursery production conditions. Specific objectives included:

1. Develop and implement a machine vision algorithm for obtaining grade classification measurements at production line rates,
2. Evaluate performance in terms of measurement speed, precision, and accuracy of classification.

METHODS AND MATERIALS

Assumptions

Several assumptions were adopted concerning the environment in which the grading would be performed. First, seedlings would be singulated, permitting only one seedling to appear within the camera field-of-view at a given time. Second, shoot orientation and lateral position would be loosely constrained. Finally, it was assumed that a black conveyor belt would be used to transport seedlings beneath the cameras.

Equipment

Equipment included a conveyor belt, machine vision computer, cameras, lenses, and lights. To simulate production grading operations, a variable-speed belt conveyor was constructed to transport seedlings for inspection. The black belt shiny surface was dulled by sanding to minimize specular reflection.

An International Robomation/Intelligence (IRI) D256 machine vision development system was used. Images were digitized into an array of 256 X 240 picture elements (pixels) with 256 grey levels. A high-speed hardware coprocessor performed computationally intensive operations such as image filtering and edge

¹ Paper presented at the Intermountain Forest Nursery Association Meeting. [Oklahoma City, OK, August 10-14, 1987]

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detection, runlength-encoding, and moments calculations. Software was developed in the C programming language.

Two Hitachi KP-120U solid-state black-and-white television cameras were employed for image acquisition. Camera 1 was used to obtain a close-up image of the seedling root collar zone. A field-of-view (FOV) approximately 12.8 cm (5 in) square provided a 0.5 mm (0.20 in) pixel resolution (fig. 1). Camera 2, with a FOV approximately 51 cm (20 in) square and resolution of 2.2 mm, acquired an image of the entire seedling.

Illumination was provided by fluorescent room lighting and strobed xenon flash. Relatively low-level room lighting was adequate for detection of the moving seedlings in the FOV of camera 2. When a seedling was detected, synchronized strobe lamps were triggered to obtain a "frozen" image with each camera.

Grading Scheme

Morphological characteristics are used in the grading of most nursery stock. These characteristics include stem diameter at the root collar, shoot height and weight, root weight or volume, root fibrosity, foliage color, presence of terminal buds, root/shoot volume ratio, and ratio of top height to stem diameter (sturdiness ratio) (Forward 1982, May et al. 1982). Stem diameter, shoot height, and root volume are generally given priority and were adopted as the grading criteria for this study. Of these three, stem diameter is typically considered most important.

To meet image processing time constraints, we decided to emphasize stem diameter measurement accuracy and obtain close approximations of shoot height and of root volume as indicated by projected root area (root area index). A classification scheme based on minimum acceptable values of these three parameters (May et al. 1982) is given in table 1. Seedlings were graded into two classes; acceptable and cull.

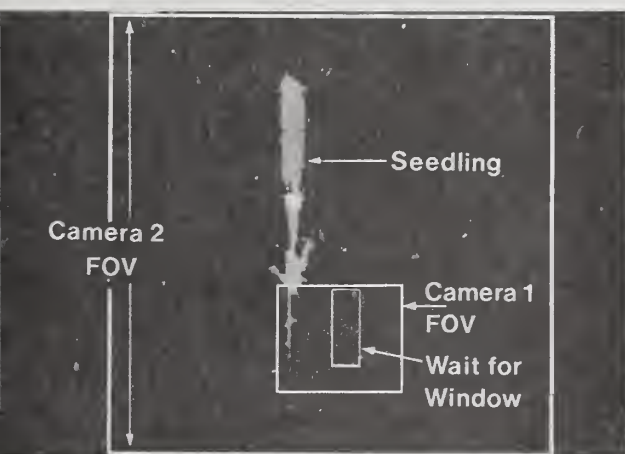


Figure 1. Field-of-view for cameras 1 and 2. Note Waitfor window.

ALGORITHM

The grading algorithm is composed of several separate tasks. These operations are: calibration, seedling detection, measurement of orientation, location of the root collar, diameter measurement, root area measurement, shoot height measurement, grade classification, and recording of seedling statistics. A detailed description of the algorithm is presented by Rigney (1986).

Accuracy of diameter measurement and the probability of the root collar appearing within the camera view influenced the choice of FOV for camera 1. Because the position of the root collar cannot be closely constrained, a relatively wide FOV is necessary. We decided to make the FOV as large as possible, while maintaining a measurement precision of at least 0.5 mm (0.20 in).

Seedling Detection

A program loop is entered in which successive images are acquired with camera 2 (wide FOV). Each image is multiplied by a template which defines a window in which seedling detection will trigger subsequent operations (Waitfor window, fig. 1). After grey-level thresholding, the area occupied inside the window is calculated. When the area exceeds a programmed number of pixels, the presence of a seedling is assumed, and an image is automatically acquired from each camera with strobe illumination.

Seedling Orientation

The image from camera 2 is next processed to determine shoot orientation on the conveyor belt. Coprocessor moments calculations provide the angle between the seedling major axis and a line perpendicular to the direction of travel. This angle is used as a correction factor in subsequent calculations of stem diameter and shoot height. Because measurement error becomes excessive at large angles, seedlings are not graded if the orientation angle is greater than thirty degrees.

Location of the Root Collar

Accurate location of the root collar is crucial for subsequent measurement of stem diameter, shoot height, and root area index. The image from camera 1 is thresholded, yielding a binary image showing the stem, roots, branches, and needles (fig. 2). This image is then runlength-encoded and processed line-by-line. The runlength code is an array of column numbers of the transitions from black-to-white and white-to-black on each line of a binary image.

If the number of transitions on a line is less than or equal to a selected variable (initially two), that line is a candidate for the root collar location. Additionally, from a priori knowledge about stem diameters, the maximum distance between paired transitions must be between 5 and 18 pixels (2.5 to 9 mm) for a line to be a root collar candidate. The root collar is located at the average of

Table 1.--Grading scheme for loblolly pine seedlings

Stem Diameter (mm)	Root Area Index (pixels)	Shoot Height (cm)	Grade
3.0 - 8.0	> 200	> 16	Acceptable
< 3.0 or > 8.0	any	any	Cull
3.0 - 8.0	< 200	< 16	Cull

the largest set of adjacent candidate lines, if that set contains at least six members. If the collar is not found using the initial value for number of transitions, the procedure is repeated for values of four and then six. When the root collar (line number) is found (fig. 3), it is stored along with the collar midpoint (column number) and number of adjacent candidate lines about the collar line.

If the root collar is still not located, the procedure is repeated after thresholding at a higher grey level. At this increased threshold, only the stem, major branches, and roots are visible (fig. 3). The use of two grey-level thresholds for collar location improves overall algorithm performance. A low threshold limits the number of candidate root collar lines for typical seedlings, reducing image processing time. A high threshold may be required to minimize the effect of needles, branches, and roots which are sometimes present in the root collar zone (figs. 2 & 3).

Measurement of Stem Diameter

Diameter measurement is performed inside a hardware window implemented about the root collar in the image from camera 1. Window size is defined by the set of candidate collar lines found in the collar location

subroutine. The windowed zone is processed with an edge detector favoring vertical edges and thresholded, resulting in a binary image of the strongest stem edges (fig. 4).

The image is then runlength-encoded. For lines which contain four or more transitions (two transitions occur at each stem edge), the two consecutive odd transitions which bracket the collar midpoint are found. If these transitions are within ten pixels (5 mm, horizontally) of the collar midpoint, the distance between the transitions is assumed to be the stem diameter on that line. When the processing of candidate lines is complete, and at least one line has provided a distance measure, the stem diameter is calculated as the average of the diameters on candidate lines.

Measurement of Root Area Index

The image from camera 2 is initially windowed from the root collar to the bottom of the image and processed with a specialized edge detector. The image is then thresholded, yielding a binary image with a maximum number of root pixels and minimum background noise (fig. 5). The number of pixels inside the hardware window is defined as the root area index.

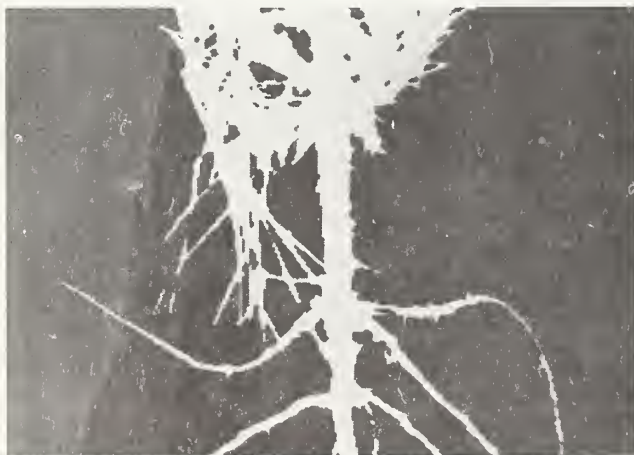


Figure 2. Camera 1 close-up image details root collar region.

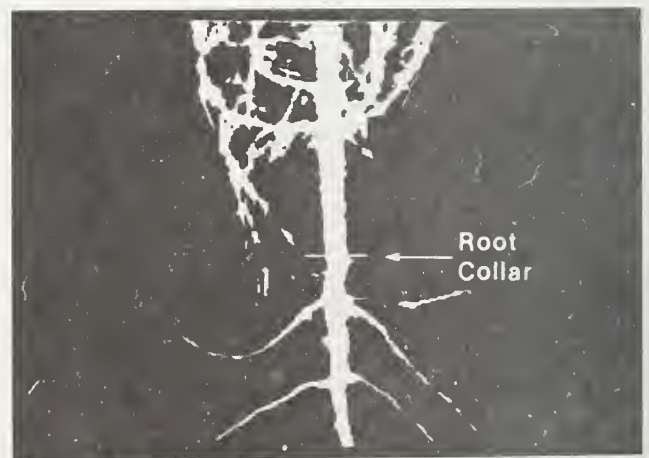


Figure 3. Algorithm locates root collar.

Measurement of Shoot Height

The image from camera 2 is thresholded and runlength-encoded. Starting at the top of the image, each line is checked to determine if the maximum distance between paired transitions exceeds five pixels. The seedling top is assumed to be located when four consecutive lines meet this criterion. Shoot height is defined as the distance between the seedling top and root collar.

Main Program

Inside the main program loop, values returned by subroutines are tested to control program flow. If all grading subroutines are successful in their respective tasks, a series of if-else statements is used to assign a grade to the seedling. Whenever a subroutine fails its task, the seedling is recorded as not gradable. Finally, measured seedling parameters, grade, and count, are written to a statistics file.

Calibration

Proper calibration of threshold values and scale factors is essential for optimum algorithm performance. The calibration subroutine initializes sixteen parameters with default values. The user is then provided an opportunity to alter the default values interactively. A wooden dowel of known diameter and length is used to calibrate scale factors. Grey level thresholds are set using a representative seedling.

EVALUATION

A reference set of 100 loblolly pine (*Pinus taeda* L.) seedlings was manually measured and graded. Stem diameters ranged from 2.3 to 6.0 mm. Performance of the machine vision system was then evaluated by grading each of the seedlings twenty times. Shoot orientation was limited to plus-or-minus thirty degrees from vertical.

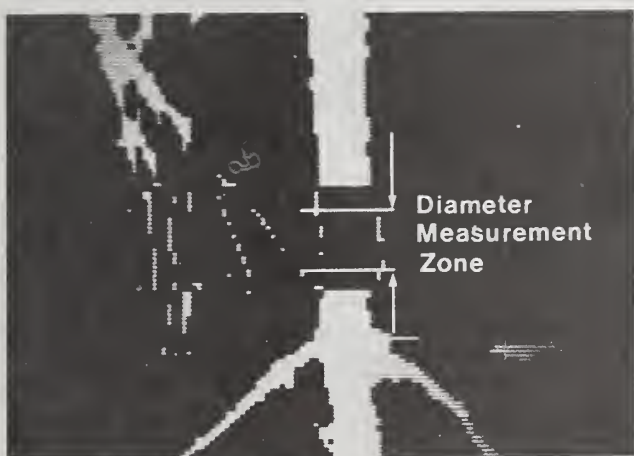


Figure 4. Image is processed to define stem edges in root collar zone.

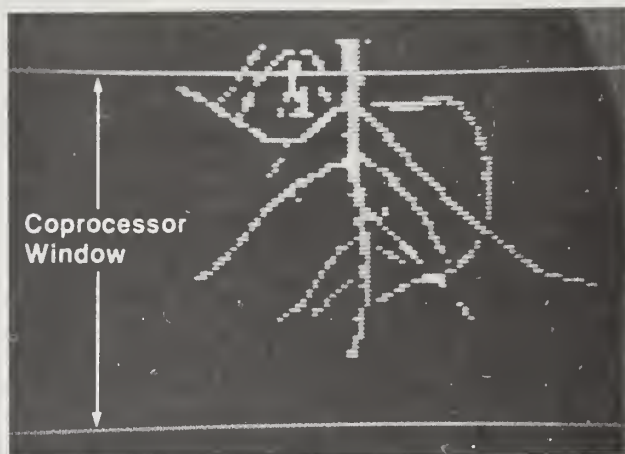


Figure 5. Image is processed to highlight seedling roots.

and root collar location was constrained to the FOV of camera 1.

Time required for the algorithm to grade a seedling averaged approximately 0.25 seconds. Strobe illumination provided reliable image capture at conveyor speeds of up to 1.0 m/s (3.28 ft/s), corresponding to a grading rate exceeding three seedlings per second. To facilitate manual placement of the seedlings on the grading belt, tests were conducted at a velocity of 0.46 m/s (1.5 ft/s).

The classification error rate averaged 5.7 percent for the set of 100 seedlings (table 2). This is very acceptable performance, bettering manual grading operations which have an average misclassification rate of seven to ten percent (Boeckman, 1986). As expected, a large part of the classification error was attributable to seedlings which straddled the borderline between acceptable and cull with respect to diameter and root area. Such seedlings comprised 17 percent of the grading test set and had an average misclassification rate of 23.2 percent. The remaining 83 seedlings had an average misclassification rate of 2.2 percent (table 2). Since there is no significant penalty for misclassification of borderline seedlings, 2.2 percent misclassification may be a better indicator of algorithm performance.

Measurement precision was excellent, considering the spatial resolutions of cameras 1 and 2, which were 0.5 mm/pixel and 2.2 mm/pixel respectively. The coefficient of variation of 20 measurement repetitions averaged 7.6, 12.2, and 4.1 percent for stem diameter, root area, and shoot height, respectively.

The few seedlings which showed the largest deviations in measured parameters were characterized either by needles extending down past the root collar, or by roots bent upward past the root collar, or both. The subroutine which located the root collar performed inconsistently on such seedlings. A few such seedlings could not be graded.

Table 2.--Percent misclassification of 100 seedlings, 20 reps

Manual Grade	Acceptable		Cull		Total		
	#	mis.	#	mis.	#	mis.	n.g.
Borderline	6	31.7%	11	18.6%	17	23.2%	2.6%
Easily Classified	63	2.2%	20	2.0%	83	2.2%	2.3%
All	69	4.7%	31	7.9%	100	5.7%	2.3

n.g. = not gradable

mis. = misclassified

We anticipate that algorithm performance could be enhanced with minor modifications. First, the shoot area could easily be measured, allowing calculation of a root/shoot ratio. Calculation of the sturdiness ratio (diameter/height) would also be straightforward. Collection of a data base with the machine vision system would allow implementation of a statistical classification scheme, leading to improved grading performance.

The measurement precision demonstrated by the algorithm suggests use for classification of seedlings into several acceptable grades. Additional grade definitions could be optimized for specific planting sites. Finally, we expect that the comprehensive statistics collected in a commercial implementation would make machine vision grading a valuable nursery management and research tool.

SUMMARY AND CONCLUSIONS

This study has demonstrated that machine vision can provide accurate production rate grading of harvested pine seedlings. Singulated seedlings were transported on a conveyor belt, with shoot orientation and root collar position loosely constrained. Seedlings were classified as acceptable or cull on the basis of stem diameter, shoot height, and projected root area.

Tests with loblolly pine seedlings revealed excellent system performance. Seedlings were graded in approximately 0.25 seconds, with an average classification error rate of 5.7 percent. These results exceed manual grading performance, which typically requires one second per seedling with an error rate of seven to ten percent. Misclassification was largely due to seedlings with borderline diameter and/or root area, and the occurrence of branches or roots in the root collar zone. Measurement precision was adequate for seedling classification into several grades, suitable for specific planting sites.

DISCLAIMER

Reference to commercial products or trade names is made with the understanding that no discrimination is intended or endorsement implied.

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Mycorrhizae Nursery Management for Improved Seedling Quality and Field Performance¹

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Abstract.--Nursery and field outplanting studies have repeatedly demonstrated that selected ecto- and endomycorrhizae on nursery seedlings reduce culls and improve field survival and growth. Mycorrhizae are significantly affected by nursery soil factors such as pH, drainage and moisture, fertility, and organic matter, and by cultural practices such as soil fumigation, cover crops, and pesticide applications. Seedling lifting, storage, and planting practices should be designed to retain the maximum number of feeder roots and associated mycorrhizae as possible. Inoculum of several species of ectomycorrhizae is commercially available, along with the necessary technology and machinery to be incorporated into standard bare-root and container nursery operations. Nurserymen and foresters are challenged to utilize mycorrhizae technology as an integral component of seedling production and forest regeneration.

INTRODUCTION

Seedling quality and field performance are largely governed by processes occurring under the soil surface in the root zone of seedlings. Absorption of water and nutrients is a function of the amount and quality of growing root tips or feeder roots. The feeder roots of most tree species are infected by specialized fungi that form beneficial associations called mycorrhizae (fungus-roots). These symbiotic structures greatly increase root absorption efficiency and are vital to the survival and growth of both the host tree and the fungus. Compared to nonmycorrhizal roots, those infected by mycorrhizal fungi have increased absorptive capacity, nutrient fixation, resistance to soil pathogens, and longevity. As the main interface between seedling and

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Figure 1.--Hardwood seedling feeder root infected with the endomycorrhizal fungus, *Glomus* sp. (left) and a mass of *Pisolithus tinctorius* (Pt) ectomycorrhizae on a southern pine seedling root (right).

soil, mycorrhizae are a key measure of root system quality and are a vital component of integrated nursery management.

Mycorrhizae are of two biological types: endomycorrhizae, which actually penetrate host cells; and ectomycorrhizae, which grow between the root cells and cover the root surface with a mantle of fungus hyphae (Fig. 1). Most hardwood

tree species, including maple, sweetgum, sycamore, ash, walnut, and poplar, along with some conifers, including cypress, redwood, and arbovitae, form endomycorrhizae and depend on them for normal growth. This mycorrhizal type occurs on all agronomic crops, including nursery cover crops such as sorghum, corn, and the grasses. Ectomycorrhizal fungi are associated with tree species which include pine, spruce, fir, alder, beech, oak, and hickory. Both ecto- and endomycorrhizal fungi have very broad host ranges.

Endomycorrhizal fungi penetrate cortical cells of infected roots and form nutrient-exchanging structures (arbuscles) inside them. A loose network of fungal hyphae grows from the feeder root surface, extending the effective area of the root system. Endomycorrhizal roots absorb and utilize nutrients, particularly phosphorous, better than nonmycorrhizal roots. Thick-walled spores (vesicles) may develop in feeder root tissue, on the root surface, or in the root zone. These microscopic "vesicular-arbuscular" (VA) mycorrhizal fungi do not modify root morphology or produce conspicuous above-ground fruiting bodies, as do the ectomycorrhizal fungi.

Ectomycorrhizal feeder roots are visibly different from nonsymbiotic roots. They usually appear swollen, forked, more prolific, and differently colored. Fungal hyphae cover the feeder root in a dense mantle. Strands of fungal hyphae radiate into the soil and to the bases of fruiting bodies produced by these fungi. Ectomycorrhizal fungi depend on their hosts for simple carbohydrates, amino acids, and vitamins to complete their life cycles and produce their spore-disseminating fruiting bodies. They benefit their hosts by increasing water absorption and accumulation of nitrogen, phosphorous, potassium, calcium, and other nutrients (Marx 1977).

Extensive mycorrhizae research conducted by the USDA Forest Service and a number of cooperating forestry agencies has identified the primary functions of mycorrhizae in tree seedling physiology and the nursery management factors that limit mycorrhizal establishment. Technology has been developed recently for the artificial inoculation of bare-root and container nurseries with selected ectomycorrhizal fungi. Several types of commercial inoculum are currently available for selected ectomycorrhizal fungi and can be operationally utilized in forest tree nurseries. Techniques have been developed to identify and quantify ectomycorrhizae occurring on seedling root systems utilizing ectomycorrhizae as a measure of seedling quality. In numerous container and bare-root nursery studies, along with forest and reclaimed mineland outplanting studies, selected ectomycorrhizae have significantly increased seedling quality and field performance. Provided with this unique technology, nurserymen, foresters, and mineland reclamation specialists are challenged to understand and utilize mycorrhizae as an integral component of nursery seedling production and forest regeneration.

BENEFITS

Ectomycorrhizae

Most conifer tree species, including all pines, cannot grow without ectomycorrhizae. This obligate dependency of trees on their fungal symbionts has been thoroughly substantiated through extensive laboratory and field research, and through unsuccessful attempts to introduce tree species into areas where their symbiotic fungi were not present. After the ectomycorrhizal fungi were introduced, trees were successfully established (Marx 1980). In forest tree nurseries in the United States, there is seldom a total absence of ectomycorrhizal fungi. Seedlings form ectomycorrhizal associations with naturally occurring fungi that originate from windblown spores produced by fruiting bodies in adjacent windbreaks, seedling beds, or forest stands. In nurseries where cultural practices or new field conditions have reduced ectomycorrhizal fungus populations, seedlings grow poorly and do not respond to increased fertilization. Pockets of seedlings that do have ectomycorrhizae or even had ectomycorrhizae established earlier in the season, have increased stem caliper and height, improved foliage color, and a more balanced shoot:root ratio than adjacent stunted seedlings which are deficient in ectomycorrhizae.

The ectomycorrhizal fungi that occur most commonly in bare-root nurseries, such as Thelephora terrestris (Tt), are ecologically adapted to the favorable growing conditions in nursery soils. However, these fungi are poorly adapted to the adverse conditions of many reforestation and reclamation sites. Research by the USDA Forest Service has focused on one particular ectomycorrhizal fungus, Pisolithus tinctorius (Pt), which is especially tolerant of extreme soil conditions, including low pH, high temperature, drought, and toxicity. The conditions, which occur on many forest sites, inhibit other naturally occurring ectomycorrhizal fungi and their host trees (Marx, Cordell, and others 1984). Pt was selected because of its adaptability, ease of manipulation, wide geographic and host range, and demonstrated benefits to trees, both in the nursery and on reforestation and reclamation sites.

Many conifer and some hardwood species on a variety of nursery sites have been artificially inoculated with Pt by treating seedling containers and prefumigated nursery seedbeds (Fig. 2). Effective Pt vegetative inoculum has consistently improved the quality of nursery seedlings. National container and bare-root nursery evaluations have demonstrated the effectiveness of several formulations of Pt inoculum on selected conifer seedling species (Marx, Ruehle, and others 1981; Marx, Cordell, and others 1984). During the past 10 years, over 125 bare-root nursery tests have been conducted in 38 states. A companion evaluation of container seedlings also demonstrated the effectiveness of commercial Pt vegetative inoculum in 18 nurseries in 9 states

and Canada. Inoculated seedlings have significantly outperformed uninoculated checks (Fig. 3) that contained only naturally occurring ectomycorrhizae (predominantly Tt). Results obtained from 34 nursery tests conducted during 3 years showed that Pt inoculation of southern pine seedlings increased fresh weight by 17 percent, increased ectomycorrhizal development by 21 percent, and decreased the number of cull seedlings at lifting time by 27 percent (Fig. 4). The nursery failures that have occurred have been correlated with such factors as ineffective Pt inoculum, excessively high soil pH (above 6.5), improper nursery cultural practices, pesticide toxicity, or severe climate (Cordell 1985).

Inoculated seedlings have been planted on routine forestation sites, strip-mined areas, kaolin wastes, and Christmas tree farms scattered over the United States. Currently, over 100 Pt ectomycorrhizal outplantings involving 12 species



Figure 2.--Abundant Pt fruiting body production between 2-0 eastern white pine seedbeds pre-fumigated and inoculated with commercial Pt vegetative inoculum.

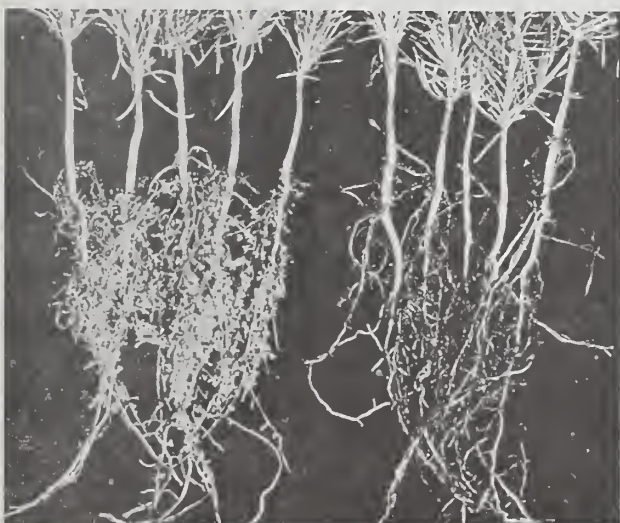


Figure 3.--1-0 loblolly pine seedlings with Pt ectomycorrhizae (left) and with only naturally occurring ectomycorrhizae (right).

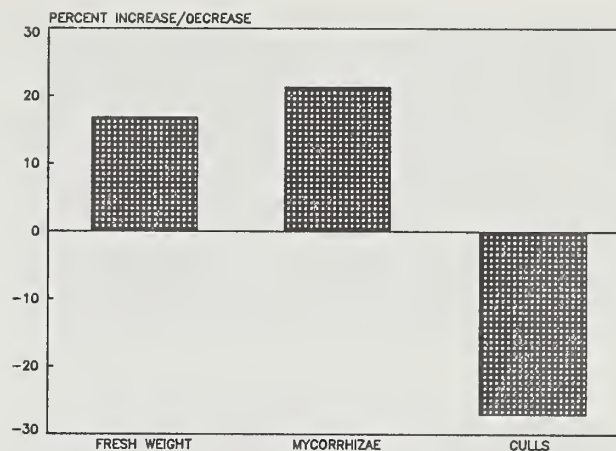


Figure 4.--Increases in seedling fresh weights and ectomycorrhizal development and decreases in the number of culls are obtained by inoculating seedlings with Pt.

of conifers are being monitored in 20 states. Over 75 of these outplantings contain southern pine species (primarily loblolly [*Pinus taeda* L.] and slash pine [*P. elliotii* Engelm. var. *elliotii*]) in the Southern United States. Most of these outplantings have been established since 1979; consequently, benefits to mature forest stands cannot be estimated. At widespread locations, however, tree survival and early growth of several conifer species have been significantly improved by Pt inoculations in the nursery. A significant increase (25+%) in tree volume is still being observed on Pt-inoculated eastern white (*P. strobus* L.), loblolly, and Virginia (*P. virginiana* Mill.) pines over check trees after 10 years in western North Carolina. Loblolly pine volume was 31 percent higher, and white pine volume was 151 percent higher than in uninoculated checks. Outplantings established by the Ohio Division of Mineland Reclamation on mineland reclamation sites in southern Ohio during 1982 and 1983 showed an average survival increase of 23 percent and 24 percent, respectively, for Virginia and eastern white pine seedlings over routine nursery seedlings after 2 years in the field. Treating longleaf pine (*Pinus palustris* Mill.) seedlings with Pt inoculum in the nursery increased their survival over uninoculated checks by 17 percent after 3 years in the field in four Southern States. Inoculation of longleaf pine with Pt, in combination with selected cultural practices in the nursery and a benomyl root treatment prior to field planting, has significantly increased the field survival and early growth of bare-root seedlings (Kais, Snow, and Marx 1981; Hatchell 1985).

After 8 years on a good-quality, routine forestation site in southern Georgia, a 50 percent increase was observed in volume/acre growth of Pt-inoculated loblolly pine over controls. The improvement was correlated with continued Pt-inoculated tree growth during seasonal periods

of severe water deficit.⁵ Similar relationships have been found in other field studies. Root systems with abundant Pt ectomycorrhizae are apparently more capable of extracting water and essential nutrients from soil during periods of extreme water stress than are root systems with fewer ectomycorrhizae or with other species of ectomycorrhizal fungi. These reported benefits do not even show the full potential of Pt, because as the fungus thrived on inoculated treatment plots and spread to uninoculated plots, treatment integrity was lost after 3 years.

Endomycorrhizae

Any nurseryman who has encountered stunted, chlorotic hardwood seedlings in a prefumigated bed, despite proper fertilization, irrigation, and disease control, is fully aware of the benefits provided by endomycorrhizal fungi. Nursery studies have repeatedly shown increases in the quality of seedlings with endomycorrhizae, compared to those without endomycorrhizae (Fig. 5). Root and stem weight of black cherry, boxelder, green ash, red maple, sweetgum, sycamore, and black walnut seedlings were significantly increased following treatment with VA mycorrhizal fungi (Kormanik, Schultz, and Bryan 1982). Black walnut seedlings grown in nursery soils infested with VA fungi retained their leaves longer, extending the effective growing season by 6 to 8 weeks and resulting in greater root and shoot biomass production (Kormanik 1985). Benefits from endomycorrhizae were greatest at phosphorous levels below 75 ppm (150 lb/acre). At higher soil phosphorous concentrations, nonmycorrhizal seedlings grew as well as endomycorrhizal seedlings (Kormanik et al. 1982; Kormanik 1985). In field studies where available phosphorous was low (10-15 ppm), hardwood seedlings that had abundant lateral roots and endomycorrhizae did not die



Figure 5.--Inoculation with a VA endomycorrhizal fungus increased seedling biomass of eight hardwood species (left) compared to noninoculated seedlings (right).

⁵Marx, D.H., C.E. Cordell, and A. Clark. 1987. Eight-year performance of loblolly pine with *Pisolithus* ectomycorrhizae on a good quality forest site. Manuscript in press. USDA Forest Service, Southeastern Forest Experiment Station, Institute for Mycorrhizal Research and Development, Athens, Ga. [Submitted to Southern Journal of Applied Forestry.]



Figure 6.--Observed correlation between increased number of sweetgum seedling primary lateral roots (\geq or $>$ 1 mm diameter) and improved seedling quality.

back as much after outplanting as those with few lateral roots and poor endomycorrhizal development. In most forest soils, long-term benefits from endomycorrhizal treatments in the nursery are difficult to determine because nonmycorrhizal root systems are quickly colonized by naturally occurring VA fungi (Kormanik 1985).

In the extended process of evaluating root system development in relation to VA fungi, a high correlation was found between the number of primary lateral roots (1 mm or more in diameter) and seedling performance after outplanting. In a 1-year-old sweetgum plantation, height, root-collar diameter, and survival increased and top dieback decreased (Fig. 6) as the number of lateral roots increased (Kormanik 1986). The previously observed correlation between the number of lateral roots and seedling quality remained consistent as additional tree species were examined. Findings may be applicable to conifers as well as hardwoods and ecto- as well as endomycorrhizal host trees. While the effects of lateral root morphology appear to be independent of mycorrhizal condition, they demonstrate the importance of assessing root systems as a component of seedling quality.

Identification and Quantification

A nurseryman who hopes to maximize seedling quality should learn to recognize and perhaps quantify the dominant mycorrhizal types occurring on seedlings. Ectomycorrhizal fungi are most easily identified by their fruiting bodies--the numerous puffballs or mushrooms that develop some time after seedlings have been colonized. The fungi can also be recognized on the basis of distinct morphology of ectomycorrhizal feeder roots. Although over 2,000 ectomycorrhizal fungi are known, only a few (1 to 3) species usually are found in a nursery. On western fir, spruce, and pine seedlings, gilled mushrooms of *Laccaria*

(Fig. 7a) and Hebeloma (Fig. 7b) species, pored mushrooms of Suillus species (Fig. 7c), and puffballs of Rhizopogon species (Fig. 7d) are common. On or near pine seedlings in the South, puffballs of Pisolithus tinctorius (Fig. 7e) and the papery thin, funnel-shaped mushrooms of Thelephora terrestris (Fig. 7f) frequently occur. Puffballs of Rhizopogon species, which have white, homogeneous centers, can easily be distinguished from those of Pisolithus tinctorius by their lack of peridioles or small sacs of spores within the context. Recognizing and separating ectomycorrhizal species on the basis of root morphology requires a trained eye, but the different colors and shapes of ectomycorrhizae can be distinguished with practice. Whereas nonmycorrhizal feeder roots are generally thin, with texture and color similar to the larger roots, ectomycorrhizae usually are swollen, forked or many-branched, and differently textured and colored from the rest of the root system.

During quantitative and qualitative seedling evaluations, a relative measure of the amount of mycorrhizal occurrence is more useful than identification of the ectomycorrhizal fungi on a sample of seedlings. Sampling techniques have been developed to estimate the proportion of a seedling's feeder roots that are ectomycorrhizal. In measured lengths of lateral roots, numbers of feeder roots with and without ectomycorrhizae are counted (Anderson and Cordell 1979). Such laborious examinations may be required for research studies, but they are impractical for estimates

of large quantities of operational seedlings. A reliable estimate can be determined by visual examination of seedling root systems that have been rinsed clean in water. An estimated percentage of ectomycorrhizal feeder roots is assayed to each seedling and averaged for the whole seedling sample. With experience, a seedling can be evaluated in a matter of seconds. These estimates provide values that can be compared among samples, inventory dates, or even different crop years. As nursery management practices are refined, it becomes possible to monitor the mycorrhizal component of seedling quality.

Unlike ectomycorrhizae, the VA endomycorrhizal fungi produce no morphological changes or structures visible to the unaided eye. Endomycorrhizae can only be identified by their microscopic hypha and vesicle morphology, and by the host association in which they occurred. In bare-root nurseries, seedling stunting, chlorosis, and top dieback are often indicators of poor endomycorrhizal development. Endomycorrhizal deficiencies may result from soil fumigation or from fungicide applications that eliminate or drastically reduce soil populations of the fungi. Endomycorrhizal deficiencies also occur in new seedling production areas with insufficient populations of appropriate endomycorrhizae. Although endomycorrhizae can be identified and quantified, monitoring for possible deficiency symptoms appearing among endomycorrhizal seedlings is more practical.

MYCORRHIZAE NURSERY MANAGEMENT

Endomycorrhizae or ectomycorrhizae in nurseries can be increased by modifying nursery management practices, as well as by artificial mycorrhizal inoculation. Guidelines for mycorrhizal nursery management pertain more to maintaining healthy seedling root systems than to the requirements of a particular species of mycorrhizal fungus. Enhancement of mycorrhizal fungi is inseparable from increased seedling quality. Management for increased mycorrhizal development is not limited solely to establishing the symbiotic structures on roots. One must consider development and retention of seedling feeder roots and mycorrhizae from seed sowing to seedling lifting in the nursery and to planting the trees in the field. Nurserymen, field foresters, and tree planters must be made aware of the two symbiotic living organisms they are handling--the tree seedling and its complement of mycorrhizal fungi.

Soil and Cultural Factors

Nurserymen strive to maintain optimal soil conditions for seedling growth. Having evolved with their host trees, mycorrhizae generally require the same moisture, fertility, and pH as the tree seedlings, but tolerance for extreme or adverse conditions does vary. Mycorrhizae are adapted to the full range of forest soils, from



Figure 7.--Characteristic ectomycorrhizal fungus fruiting bodies of (a) Laccaria sp., (b) Hebeloma sp., (c) Suillus sp., (d) Rhizopogon sp., (e) Pisolithus tinctorius, and (f) Thelephora terrestris.

heavy clays to coarse sands, but their responses to nursery practices vary with the soil type. For example, ectomycorrhizae on southern pine seedlings in deep sands may have much reduced tolerance of the systemic fungicide triadimefon (Bayleton) as compared to ectomycorrhizae occurring in clayey nursery soils. Soil fumigation with methyl bromide formulations is generally more effective in lighter, sandy soils than in heavy clays, which bind the chemical and prevent complete penetration. Similar interactions between soil texture and composition and mycorrhizae may occur for other cultural practices, including irrigation, fertilization, and application of other pesticides.

Soil pH

The pH of nursery soils has a profound effect on mycorrhizal establishment and growth. As a measure of the balance of acid and basic chemical activity in a soil, pH indicates limitations to the availability of nutrients, the pattern of nutrient absorption and exchange in the root zone, and even the composition of micro-organisms (mycorrhizal fungi, saprophytes, and soil pathogens) in the root zone. Although mycorrhizal synthesis occurs on trees in soils with wide pH ranges throughout the world, pH of nursery soils should approximate the optimum for the tree species and the forest soil type. For endomycorrhizae on hardwoods, Kormanik (1980) recommended maintaining soil pH between 5 and 6. He cited a study in which satisfactory endomycorrhizal synthesis and sweetgum seedling growth occurred at pH 4.5 and 5.5, but not at pH 6.5 or 7.5. Ectomycorrhizae also are usually favored by slightly acidic soils, and some, such as *Pt*, are severely inhibited by soil pH over 6.5. Most ectomycorrhizal fungi have a pH optimum between pH 4 and 6 when grown in pure culture, but by manipulating the amount and chemical formulation of nutrients, this range can be extended or shifted to more acidic or alkaline pH optimums.

The indirect effect of soil pH on nutrient availability in soils may be more important in mycorrhizae formation than the direct effects of pH on the fungus (Slankis 1974). All the macronutrients are more available above pH 6. *Pt* thrives in nursery soils under standard fertilization regimes, at pH 4.5 to 5.5, and on acid mine spoils with soil pH as low as 3. Vegetative inoculum formulations of *Pt* produced at pH greater than 6.0 were not as effective as inoculum produced at pH below 6.0 (Marx et al. 1984). An additional hazard of high soil pH in the production of both conifer and hardwood seedlings is the increased activity of soil pathogenic fungi, such as *Fusarium* and *Pythium*, which cause damping off and root rot.

Soil Drainage and Moisture

For satisfactory mycorrhizal development and seedling growth, nursery soils must have adequate soil drainage but sufficient soil moisture. In

dry soils, free water is unavailable to roots, and nutrient absorption and exchange stop. However, irrigation generally maintains adequate soil moisture for seedling growth. In soils with excess water, oxygen deficiency inhibits the growth of both symbiotic fungi and tree roots. Respiration is greater in mycorrhizal roots than in noninfected roots. Prolonged flooding profoundly changes root physiology, decreasing phosphorous fixation, decreasing permeability to water and nutrients, arresting growth, and eventually killing roots (Slankis 1974). Seedlings grown in poorly drained soils are subject to damping off and root rot diseases caused by fungi with spores motile in water, such as *Pythium* and *Phytophthora*. Where drainage is poor, soil conditions must be improved by leveling, subsoiling, or adding amendments.

Soil Fertility

As with other soil factors influencing mycorrhizal development, fertility should be maintained at levels required for ample host seedling growth. Excessively high levels of certain nutrients, particularly nitrogen and phosphorous, may change chemical balances within seedling root systems, limiting mycorrhizal infection. As pH rises above 6, high phosphorous and nitrogen levels may be especially discouraging to mycorrhizal fungi. With soil pH at or below 6, however, seedlings grown under high fertility (especially nitrogen) have produced abundant *Pt* ectomycorrhizae. Hardwood seedlings grown under high phosphorous fertility (greater than 200 ppm) have reduced endomycorrhizal synthesis (10-35% down from 40-75%) without reducing seedling growth. Kormanik (1980) recommends maintenance of 75 to 100 ppm phosphorous for good hardwood seedling and VA mycorrhizal development. Kormanik also recommends up to 10 applications of nitrogen, totaling 500 lb/acre, scheduled to capture late season height growth of hardwood seedlings following root development. Increasing total nitrogen from 250 to 500 lb/acre was accompanied by a 50-percent increase in height growth and approximately a 40-percent increase in root collar diameter of endomycorrhizal sweetgum seedlings, justifying the added nitrogen cost.

Soil Fumigation

Effective soil fumigation is necessary to control against weeds, nematodes, insects, and injurious soil fungi. Unfortunately, fumigation also kills existing populations of mycorrhizal fungi. Ectomycorrhizal fungi are quickly replenished by high numbers of windblown spores from mushrooms and puffballs. Replenishment occurs so readily in most nurseries, that spring rather than fall fumigation is required before artificial ectomycorrhizae inoculations to minimize competition from these naturally occurring fungi.

Spread only by physical movement of soil and water, endomycorrhizal fungi are slow to return

to prefumigation levels. VA fungi populations are highly variable in fumigated areas and build up in the soil only after one or more crops are grown. By growing cover crops between soil fumigation and sowing of tree seedlings, endomycorrhizal populations are at effective levels for seedling production. If certain soil pathogens, such as *Cylindrocladium* sp., were not of greater danger than having insufficient endomycorrhizae, soil fumigation should be avoided all together.

Cover Crops

In addition to building up endomycorrhizal populations, cover crops between seedling crops rest the soil, increase organic matter content, and improve soil structure. Crops of corn, sudex, sorghum, millet, or grasses are effective in building up VA fungi in the plant roots and in soil. Winter as well as summer cover crops will increase endomycorrhizae. Although sorghum induced highest densities of VA fungal spores, sweetgum seedlings grown in compartments planted with corn, millet, sudex, and sorghum were of comparable quality and size (Kormanik, Bryan, and Schultz 1980). Crops with longer growing seasons have greater potential for root growth and spore production. Use of any cover crop after fumigation must be accompanied by careful monitoring of any chronic soil-borne disease problems that may occur in particular nursery soils.

Pesticides

Many pesticides of various types are used in nurseries, and the effects of individual chemicals on seedling growth or mycorrhizal synthesis are seldom known. The effects of herbicides and insecticides on mycorrhizae are particularly unexplored. However, many effects of commonly used fungicides have been documented. The fungicides captan and benomyl are recommended for use in conjunction with operational Pt inoculation of bare-root nurseries. Metalaxyl (Ridomil or Subdue), an effective fungicide against *Phytophthora* root rot, has no deleterious effect on ectomycorrhizae on Fraser fir when used at recommended dosages. Perhaps the most widely used fungicide in southern pine nurseries is the systemic fungicide, triadimefon (Bayleton), used to control fusiform rust. Triadimefon seed treatments which provide rust control through southern pine seedling emergence, have no negative impact on naturally occurring or artificially-introduced ectomycorrhizal fungi. However, foliar applications applied three to four times during the rust season (May-June) suppress ectomycorrhizal development until late in the growing season. Pt ectomycorrhizae are particularly susceptible to this fungicide. Normally, by lifting time, naturally occurring ectomycorrhizae, mostly *Thelephora terrestris*, have recolonized the root system. Negative impact on seedling quality is hotly debated, but the effects on mycorrhizae are well substantiated. Any and all pesticides, prior to operational use in nurseries, should be

evaluated for their effects on mycorrhizal development as well as seedling growth.

Shading

Shade-tolerant conifer seedlings require some degree of physical shading. Too much shading reduces photosynthesis and soil temperatures to the degree that mycorrhizae cannot form. The optimum level of shade must be found that protects seedlings from scorching but does not inhibit mycorrhizae.

Root Pruning

At the proper depth and distance from seedlings, root pruning stimulates formation of compact root systems and increased mycorrhizal development. Injury of the root tips initiates greater carbon allocation to the root system, which causes the increased root growth. This practice increases the amount of mycorrhizal feeder roots proximal to the seedling stem, effectively increasing the amount of mycorrhizae that will be retained with the seedling during lifting and handling.

Seedling Lifting, Storage, and Planting

Special care must be taken during all stages of seedling handling to maintain sufficient root systems and mycorrhizae. Mycorrhizae are delicate structures. They can be ripped off and left behind in seedling beds during lifting, desiccated in storage, or cut off prior to field planting. For sustained seedling quality, lifting and handling techniques must be modified to minimize damage to feeder roots and mycorrhizae. Stripping of roots adds severe negative impacts on seedling field performance (Marx and Hatchell 1986). Full bed seedling harvesters are less destructive than single- or double-row lifters. Condition of the root systems should be checked during the entire lifting process; even slight reductions in tractor speed can greatly reduce damage to the roots as seedlings are lifted.

During transfer of seedlings from the field to the packing room and at all other times when seedlings are handled, special care is required to avoid drying of the roots by exposure to wind and sun. The procedure by which seedlings are packed influences their ability to endure storage and survive field planting. If extended storage is required, Kraft paper bags with a polyethylene seal will maintain seedling moisture better than seedling bales. Cold storage is vital to slow seedling respiration. Studies comparing packing material have determined that seedling survival is better when peat moss, clay, or inert super-absorbents are used rather than hydromulch (Cordell, Kais, Barnett, and Affeltranger 1984). The material should be distributed through the bag, not simply dumped at the bottom or top. Better results are obtained when all root systems are coated or at least in contact with the pack-

ing material. Numerous studies have documented the effects of long-term storage on seedling quality. For most tree species and their mycorrhizae, storage for 2 to 6 weeks is not harmful. Beyond the threshold for each species, however, significant negative effects can occur.

Seedling quality is vulnerable to any one or more limiting factor. Even if quality is maintained through seedling growth, lifting, and storage, it could still be severely reduced by improper transportation to the planting site or rough handling during planting. Tree planters should understand proper planting methods and the reasons for them. Where possible, seedlings should be transported under refrigeration. If that is not possible, they should be covered and stacked with spacers to avoid high temperature buildup inside the seedling containers. For machine or hand planting, root pruning at the planting site should be avoided because it eliminates carefully nurtured feeder roots and mycorrhizae. High temperature, high winds, and low humidity kill feeder roots and mycorrhizae very rapidly. The first priority in planting should always be to maintain seedling viability and vigor. The rate at which acres are planted is of no consequence if the seedlings do not survive.

Ectomycorrhizal Fungus Inoculations

Ectomycorrhizal Fungus Inoculum

Until recently, artificial inoculation of Pt or any other ectomycorrhizal fungus species was limited because procedures, commercial fungus inoculum, and necessary equipment were not readily available to nurserymen. The USDA Forest Service has been cooperating with several private companies to develop different types of commercial ectomycorrhizal inoculum, along with equipment and procedures needed for inoculating bare-root and container-grown seedlings. In addition to Pt ectomycorrhizal inoculum, strains of *Hebeloma* sp., *Laccaria* sp., and *Scleroderma* sp. are currently available. The types of Pt inoculum that are available are vegetative inoculum from Mycorr Tech, Worthington, Pennsylvania, spore pellets, spore-encapsulated seeds, and bulk spores from either International Forest Tree Seed Co., Odenville, Alabama, or SouthPine, Inc., Birmingham, Alabama. A nursery seedbed applicator (Fig. 8) has been developed to accurately place Pt vegetative inoculum in seedbeds prior to sowing in bare-root nurseries. Inoculum is applied in bands under seed rows at desired depths (Fig. 9). Use of the applicator has reduced the amount of vegetative inoculum needed by 75 percent and reduced time and labor requirements as compared to broadcast application.

Inoculum Costs

There is a wide range in the cost of commercial Pt inoculum (Table 1). Cost of the each inoculum type also varies with such factors as

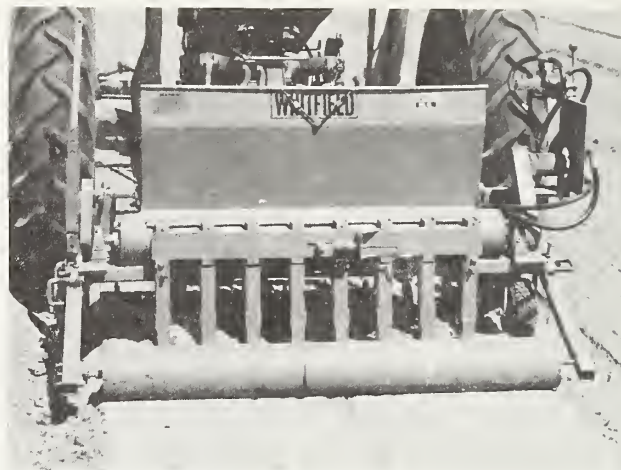


Figure 8.--A commercially available machine applies bands of commercial Pt vegetative inoculum to a bare-root nursery seedbed.



Figure 9.--Diagram of a bare-root nursery seedbed shows bands of Pt vegetative inoculum under seedling rows in root zones.

Table 1.--Commercial Pt inoculum costs.¹

Pt inoculum type	Inoculum cost per		
	1,000 seedlings	planted hectare	planted acre
Vegetative mycelium	\$10.00	\$17.94	\$7.26
Spore-encapsulated seeds	\$ 2.22	\$ 3.98	\$1.61
Spore pellets	\$ 2.75	\$ 4.93	\$2.00
Double-screened ² bulk spores	\$ 0.43	\$ 0.77	\$0.31

¹Cost estimates are for loblolly and slash pine bare-root nurseries (269 seedlings/m² or 25 seedlings/ft²) and forest plantings (1.8 x 3.0 m or 6 x 10 ft. spacing; 1,794 trees/ha. or 726 trees/ac.) in the Southern United States.

²Double screening is required for even flow through spray nozzles. Standard bulk spores are only screened once.

nursery seedling density, seed size for spore-encapsulated seeds, and field planting spacing. In 1987, the Pt vegetative inoculum costs for bare-root nurseries per unit of forest product were reduced 25 percent by increasing nursery seedbed inoculation efficiency, improving effectiveness of inoculum, and decreasing application rates. The vegetative mycelium is sold on a volume (liter) basis, while the spore inocula are all sold on a weight (pound) basis.

Inoculation Procedures

Operational procedures vary among the different commercial Pt inoculum types, but with any inoculum, the biological requirements of a second living organism are added to those of the seedling. Special precautions are necessary for shipping, storing, and handling the Pt inoculum, as well as for lifting, handling, and field planting of seedlings. For successful Pt inoculation in bare-root seedbeds, populations of pathogenic and saprophytic fungi and native ectomycorrhizal fungi that may already be established in the soil must be reduced by spring soil fumigation. Prior to spring sowing, vegetative inoculum can be broadcast on the soil surface and incorporated into the fumigated seedbeds or it can be machine-applied with greater effectiveness and efficiency. For container-grown seedlings, vegetative inoculum can be incorporated into the growing medium before filling the containers or placed at selected depths in the growing medium in the container. Bulk spores can be sprayed, drenched, or dusted onto growing medium for containerized seedlings and onto seedbeds in bare-root nurseries. Spore pellets can either be incorporated into the growing medium or seedbed soil, or they can be broadcast on the soil surface, lightly covered, and irrigated. Spore pellets have been applied at several nurseries with a standard fertilizer spreader (Fig. 10). Spore-encapsulated seeds can be sown by conventional methods. A major disadvantage of the Pt spore inoculum is the absence of a reliable means of determining or controlling spore viability. Consequently, Pt ectomycorrhizal development has been considerably less consistent and effective with spore inoculum than with vegetative inoculum.

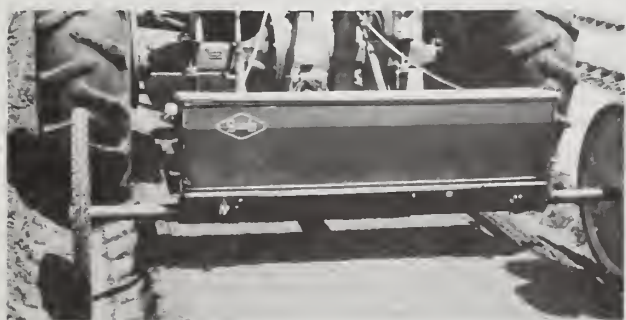


Figure 10.--Commercially available Pt spore pellets are applied to a nursery seedbed with a standard fertilizer applicator.

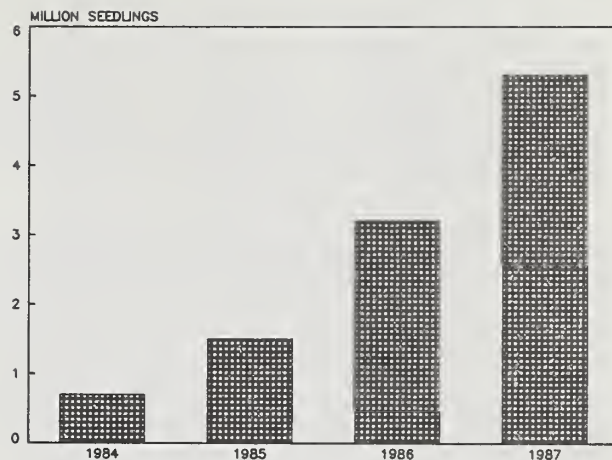


Figure 11.--Increased Pt-inoculated custom seedling production in bare-root and container seedling nurseries, 1984-87.

Operational Applications

The demand for Pt-tailored nursery seedlings has significantly increased during the past 4 years, despite the added costs and financial difficulties that most forestry agencies are currently experiencing. Since 1984, annual demand for tailored seedlings has increased 10-fold from 0.5 million to 5 million seedlings (Fig. 11). During the spring of 1986, Pt vegetative inoculum was operationally applied at 10 bare-root nurseries in the Southern and Central United States. Approximately 2 million seedlings of 9 conifer and 1 hardwood species were produced. In addition, over 1 million pine seedlings were inoculated with spore pellets. During the spring of 1987, Pt vegetative inoculum was applied at five bare-root nurseries in the Southern and Central United States. More than 3 million seedlings of five conifer and one hardwood species were inoculated. More than 2 million seedlings are being produced at a South Carolina State nursery for the USDA Forest Service, Savannah River Forest Station, and the United States Department of Energy. This represents the largest single application of an ectomycorrhizal fungus in a forest tree nursery to date. Over 2 million additional pine seedlings were inoculated with spore pellets at two bare-root nurseries in North Carolina and South Carolina and a container seedling nursery in Alabama.

Endomycorrhizal Fungus Inoculations

Although the technology required to produce VA mycorrhizal inoculum and to inoculate soils and plants is available and in use on certain agricultural and orchard crops that are highly dependent on endomycorrhizae, artificial inoculation of forest tree seedlings is not generally feasible. For most tree species, the phosphorous threshold is low enough that increased fertilization can remedy the effects of endomycorrhizal deficiencies. In addition, within several

months, indigenous VA fungi on most reforestation sites colonize root systems of seedlings that were deficient in endomycorrhizae at the nursery. However, artificial inoculation may be beneficial if continued endomycorrhizal deficiencies and subsequent reductions in seedling quality occur at a nursery despite modifications in fertilization, fumigation, and crop rotation.

Different methods of artificial inoculation with variable potential benefits may be utilized. Nurserymen can add endomycorrhizal forest soils to the nursery soil, add soil from an area previously used to produce endomycorrhizal seedlings, or build up VA fungi populations through cover cropping. Soil or roots from the cover crop area can be spread over a deficient area and tilled into the soil. A potential problem with any of these methods is that soil pathogens can be introduced or increased by the same processes that introduce or increase VA fungi. Commercially available pot cultures of endomycorrhizal hosts grown under aseptic conditions can provide potentially cleaner and more effective inoculum consisting of soil and roots. Various types of VA fungal inocula are currently produced by NPI (Native Plants, Inc.), Salt Lake City, Utah 84108. This endomycorrhizal "starter" inoculum can be used to introduce appropriate VA fungi into fumigated or naturally deficient soils. Cover cropping can then be used to build up the VA fungal populations to effective levels for the production of endomycorrhizal seedlings.

CONCLUSION

Symbiotic relationships between tree seedlings and mycorrhizal fungi are the rule in nature. Conifer and hardwood nursery seedlings require adequate quantities and quality of either ecto- or endomycorrhizae to meet seedling quality standards. Minimum quantities or amounts of mycorrhizae are required to provide adequate field survival and growth. For southern pines produced in bare-root nurseries, this minimum ectomycorrhizae quantity has been established at 35 percent of the total seedling feeder roots on 90 percent or more of the seedlings. It should be emphasized that this 35 percent must be present when the pine seedlings are planted in the field. The quality of ectomycorrhizae for a planting site depends on the host tree-fungus species combination; optimum combinations can be produced by inoculating seedlings for specific applications, such as mineland reclamation. Custom production of mycorrhizal seedlings has been incorporated into bare-root and container nursery operations. The quality of mycorrhizae and of seedlings can also be improved through careful management of existing ecto- or endomycorrhizae.

Regardless of the selected alternatives, nurserymen, field foresters, and tree planters must be aware that they are dealing with two symbiotic living organisms--the tree seedling and the mycorrhizal fungus. Both must be nurtured to provide seedlings of the highest quality for field

forestation. The tree seedling-mycorrhizal fungus symbiotic relationship is an integral component of nursery seedling production. Any estimates of seedling quality that exclude quantitative and qualitative mycorrhizal assessments are incomplete and unrealistic.

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Integrated Pest Management in Forest Nurseries¹

T. H. Filer, Jr. and C. E. Cordell²

Abstract.--INPM techniques and procedures provide the necessary information to assist nursery managers in planning the most effective practices to produce quality seedlings. An integrated program that considers the following factors will minimize losses from diseases, insects, and weeds: site selection, fumigation, crop rotation, cover crops, sowing date, fertilization, irrigation, seedbed density, and chemical and biological control methods.

INTRODUCTION

Conservation reserve and other tree planting programs have caused an accelerated rate of reforestation in the United States, which has caused an increase in seedling production. New state and industry nurseries are being established, as well as old ones being expanded. More than 80 industry, state, and federal nurseries in the South produce over 1 billion seedlings annually. This represents over 75% of the total annual bare-root production in the United States. Nurseries grow a wide variety of both conifers and hardwood species.

Increased production and tree species confront nursery managers with a wider array of potential pest problems. The high value of genetically improved seedlings has significantly increased the impact of pest problems.

Seedling quality represents the most important economic aspect of forestation. However, seedling cost will average less than 15% of total plantation establishment cost per acre. To meet future wood demands, high quality and quantity of tree seedlings must continue to be available to the forest manager.

Major pest problems in the nursery are an exception rather than the rule. When major problems do occur, nursery managers can utilize integrated pest management practices.

The integration of suitable techniques and procedures into one concerted, harmonious effort is needed for effective, efficient control of nursery pests.

Integrated Nursery Pest Management (INPM) is defined as the reduction of pest problems in the nursery by employing decisions, plans, and a combination of management procedures in a coordinated pest management program. This system, to be successful, requires a systematic, interdisciplinary approach from such related disciplines as soil science, silviculture, forest pathology, entomology, and weed science. Emphasis must be placed on pest prevention, containment, and exclusion.

Nursery pest management practices are closely related to and must be harmoniously used with prescribed cultural practices to be practical and effective. The selection of the most effective, practical, and environmentally safe combination of INPM practices for target pest problems is the key to successful pest management.

PREVENTION

An effective quarantine program will prevent the transfer and spread of pathogens, nematodes, insects, and weeds into nursery and field forestation areas. These pests may be present on seeds, seedlings, soil, water, equipment, or personnel. Preventive measures represent the most effective and efficient pest management practice.

PEST DETECTION, DIAGNOSIS, AND EVALUATION

Early pest detection, combined with rapid diagnosis of problems, is a prerequisite to successful nursery pest management. Rapid diagnosis will permit the selection and timely application of control procedures before the pest becomes unmanageable.

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NURSERY SITE SELECTION

Selection of the nursery site is the most important cultural practice for consideration in the nursery pest management plan. Select new locations or expand existing nurseries only after considering the following factors and their relationship to pest management: soil types, texture, pH, past land use, presence of harmful pests, adequate supply of clean water with proper pH. The soil type for most tree species should be of a coarse texture, primarily sand with some silt and a low clay content. The soil profile should not have any impermeable subsoil. This type of soil promotes good tillage, fumigation, and drainage. Pre-emergence damping-off, caused by soil-borne fungi, is less severe in coarser soil with good drainage. The pH of soil and irrigation water can influence the development of soil-borne diseases. Pre- and post-emergence damping-off diseases often occur in conifers when the soil pH exceeds 6.0.

CROP ROTATION

Crop rotation is used in INPM programs to reduce seedling losses from fungi, insects, nematodes, and weeds. The pests often become serious problems when continuous seedling production is practiced without rotation. Alternating susceptible and nonsusceptible crops in proper sequence will minimize seedling losses. The alternation of cover crops with seedling production is standard practice in many forest tree nurseries.

COVER CROPS

Cover crop species vary in their susceptibility to different root rot pests. Corn, peas, soybeans, and sorghum are susceptible cover crop hosts for charcoal root rot of conifers (Seymour and Cordell 1979). Alfalfa, soybeans, and other legumes are susceptible to the *Cylindrocladium* root rot fungus of hardwoods (Cordell and Skilling 1975).

To allow for adequate decomposition, cover crops should be plowed under a minimum of 2 months before fumigation. Non-decomposed organic matter will absorb large quantities of fumigants, thereby reducing pest control. Organic matter amendments may reduce root pathogens because increased organic matter promotes high populations of saprophytes and soil organisms that compete with root pathogens.

ORGANIC MATTER AMENDMENTS

Annual applications of organic matter to nursery beds help to improve tilth, nutrient, water retention, and soil aeration. However, precautions are required concerning the type and composition. The addition of fresh sawdust or pine bark may have adverse effects on tree seedling development by changing the carbon/nitrogen ratio of the seedbed. Micro-organisms tie up the available nitrogen and the seedlings suffer from nitrogen deficiency.

SOIL AND WATER PH

Soil pH, excessively high or low, influences the severity of diseases caused by soil-borne fungi. The addition of elemental sulfur is useful to lower soil pH and reduce disease losses such as damping-off on conifer and hardwood seedlings. The addition of lime will increase the soil pH to more desirable levels. The pH of irrigation water can be lowered by metering sulfuric or phosphoric acid into the irrigation system. Desirable soil and water pH levels range between 5.0 and 6.0.

SEEDBED SOWING DATES

Minimize seedling losses from soil-borne pathogens by selecting the proper planting date. Cold, moist soils are conducive to growth and development of *Pythium* and *Phytophthora* fungi that cause pre- and post-emergence damping-off of seedlings (Filer and Peterson 1975). A delay in spring seeding until soil temperatures are favorable for seed germination will often avoid losses from damping-off fungi.

In the southern states, an equally serious problem is high soil surface temperature in late spring, which causes sun scald of young seedlings. Fall sowing is an alternative choice to avoid sun scald problems of several hardwood species.

SEEDBED DENSITY

The correct seedbed density will reduce certain pest problems. Seedbeds planted too dense, increasing competition for the available soil nutrients and water, will result in reduction in seedling growth and vigor. Poor seedling vigor increases susceptibility to diseases and insects. High seedbed density also reduces air circulation, which results in more foliage diseases. The increased demand for seedlings to meet accelerated reforestation programs suggests a possible trend to denser nursery seedbeds.

MULCH FUMIGATION

Mulches, such as pine needles and grain straw, should be fumigated to eliminate pathogenic fungi, weed seeds, and nematodes. Sanitation by fumigation prevents unnecessary introduction into the seedbed of pathogenic fungi, insects, and other pests. If pine needles, etc., are used for mulch, fumigate under tarp with methyl bromide 98% - chloropicrin 2% or methyl bromide 67% - chloropicrin 33% at the rate of 1 pound per cubic yard of mulch. Aerate the mulch at least 48 hours before it is applied to nursery beds.

FERTILIZATION

Fertilizer composition, rate, timing, and application methods can have adverse or beneficial effects on disease problems. Sub-optimal rates, inadequate formulation, and improper use of fer-

tilizer often results in seedling stunting, yellowing, poor root development, and mortality. Excess nitrogen application in early spring in soils deficient in calcium and phosphorus may increase seedling damage by damping-off fungi. Excessive levels of phosphorus (200 lbs. available P_{2O_5} per acre) will inhibit both naturally occurring and artificially inoculated ecto- and endomycorrhizae on conifer and hardwood seedlings.

SANITATION

Sanitation is an important practice in nursery pest management to prevent the spread of pest problems within the nursery and to field plantings. The practice includes roguing diseased seedlings and weed species in seedbeds. Existing susceptible windbreak species may require elimination to avoid build up of fungus inoculum and insects. Weed-free riser lines and fence roads will help reduce the spread of weed seeds, fungi, and insects into the nursery bed.

SEEDLING GRADING AND CULLING

Grading of seedlings before packing will minimize the transport of pest-infested seedlings to the planting site. Conspicuous root, stem, and foliage diseased seedlings should be culled in the packing shed. Particular seedling grading and culling efforts should be afforded potentially significant pest problems, such as the root rots (charcoal - *Macrophomina phaseolina*, *Cylindrocladium* - *Cylindrocladium* spp., and phytophthora - *Phytophthora* spp.) and southern pine fusiform rust (*Cronartium quercuum* f. sp. *fusiforme*) (Rowan, Cordell, and Affeltranger 1980). Although it is costly, nursery managers who have eliminated seedling grading in packing sheds should consider reinstating this practice when severe pest problems appear.

BIOLOGICAL AGENTS

Biological techniques represent one of the most desirable INPM practices, but effective pest control procedures are very limited for nursery production. Perhaps the best example of biological application in nurseries involves the artificial inoculation and/or management of selected mycorrhizal fungi to increase seedling quality (Cordell and Webb 1980).

Most micro-organisms in the soil are either saprophytic or nitrification agents. Some micro-organisms are antagonistic or competitive with soil-borne pathogens. Without sufficient populations of these beneficial microflora, organic matter decomposition and nutrient fixation are greatly impeded. Most of the organisms are the pioneer colonizers of recently fumigated soil. Their presence is essential for the conversion of ammonia nitrogen to the nitrate form, which can be used by seedlings.

CHEMICAL TREATMENTS

Chemical treatments involve a variety of pre- and post-planting pesticide applications. Although the use of pesticides is considered a significant component of INPM, pesticides should be used only when other INPM procedures are not available or have failed to give satisfactory control of pests.

SOIL FUMIGATION

Soil fumigation is the most effective chemical control technique for a variety of soil-borne nursery pests, including soil fungi, insects, nematodes, and weeds. The most effective soil fumigants are the methyl bromide-chloropicrin formulations. The methyl bromide 67% - chloropicrin 33% formulation is most effective in controlling root pest problems and certain weeds and grasses, such as nutsedge. Additional benefits from thermal energy can be obtained by allowing the tarp to remain on the seedbed after fumigation for 10 to 14 days or until the beds are prepared for planting.

SEED TREATMENT

In southern nurseries, most pine seeds are coated with Thiram fungicide-latex sticker to retard damping-off and repel birds. Thiram at the rate of 2 pounds per 100 pounds of seed is commonly used. For the control of fusiform rust in southern nurseries, the systemic fungicide triadimefon (Bayleton) is presently being used as either a liquid seed soak or dry powder coating to protect the young pine seedlings during the first few weeks following emergence (Rowan and Kelley 1983).

PROTECTIVE FOLIAGE SPRAYS

There is often a need for protective foliage sprays to control foliage diseases and insects on both conifer and hardwood seedlings (Smyly and Filer 1973). However, only a relatively few chemicals are available for effective and practical control of foliage pest problems. Effective control of foliage diseases requires complete and continuous coverage of the susceptible foliage during the fungus infection period when using a protective contact fungicide. However, effective control of fusiform rust can be obtained with reduced applications (i.e., 3 to 4 well-timed sprays) of the systemic fungicide triadimefon (Rowan and Kelley 1983).

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The USFS Reforestation Improvement Program¹

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Abstract.--The program applies state-of-the-art equipment and methods to input weather, culture, growth, quality, handling, and field data into a computerized database at each Forest Service nursery. The ultimate goals of the program are to increase efficiency, improve reforestation success, and lower costs.

INTRODUCTION

The Reforestation Improvement Program (RIP) is a combined effort of the three divisions of the USDA Forest Service -- National Forest System, Research, and State & Private Forestry -- to improve nursery seedling quality and plantation survival and growth. The concept is to use state-of-the-art data logging and computer technology to monitor selected seedlots and determine the relationships among environmental conditions, nursery culture, seedling handling, seedling characteristics, and performance after outplanting. This information will be used to refine nursery and reforestation practices, develop a continuing quality control system, and identify knowledge gaps that require research.

Following the Seedling Quality Workshop at Oregon State University in 1984, representatives from the three divisions of the Forest Service discussed the agency's nursery program and the research needed to improve the production of quality bareroot stock. In January 1985, a team of nursery managers and research scientists developed a draft proposal to implement RIP. The final proposal was approved, all 11 Forest Service nurseries agreed to participate, and plot establishment got underway by spring 1986. This paper describes the objectives, procedures, and current status of the program.

JUSTIFICATION

RIP was begun at this time for several reasons. The National Forest Management Act of 1976 requires that the successes and failures in our reforestation program be clearly documented and reported to Congress. Responsibility for successful reforestation has been included in line officers' performance standards. We are making more detailed evaluations of plantation survival and growth, and the results of these evaluations have dramatically increased the visibility of our reforestation program. The "Productivity Improvement Analysis of Reforestation" report published in 1983 states that a 10-percent reduction in reforestation failures in the National Forest System would save \$2,624,000 annually and that a 50-percent reduction would save more than \$13,000,000 annually. Assuming at least a 10-percent improvement in reforestation success, the program is easily justified on a purely economic basis. This is, of course, desirable, but we feel that the public image and professional reasons for improving reforestation success are even more important.

MAKING A CASE FOR MONITORING

Quality monitoring is done in most industries where market competition, liability, and reputation are important factors. In our "industry", the reasons for monitoring are (1) our desire to refine and improve, (2) our pride and reputation, and (3) our accountability. Beyond these compelling reasons, monitoring is impetus for professional growth. Without recording our inputs and their effects, our expertise grows slowly, because we have no clear records of the factors that contributed to our successes and failures. With monitoring implemented we can learn from both our successes and our failures, and readily pass that expertise on to our associates and successors.

Many plantation failures are difficult if not impossible to explain with the data presently

¹Paper presented at the Intermountain Forest Nursery Association Meeting, Oklahoma City, Oklahoma, August 10-14, 1987.

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collected. We simply do not know if the problems are occurring at the nurseries, during shipping and handling, during planting, or if they are due to site factors or lack of seedling adaptation. As always, more research is needed to provide answers, but research may not be enough. Presently, the minds of experienced nursery managers and foresters are the databases that hold the wisdom gleaned from years of experience. Two unavoidable problems with this tradition are (1) the memory is volatile, and (2) the databases eventually transfer or retire. To progress from here, we need to develop computerized databases to store the volumes of existing and future data and efficiently put them at our disposal. Once a fairly complete database is developed for each nursery, and research has adequately filled in the important gaps in our knowledge, we will be in a position to attain higher level goals such as: (1) tailoring culture to unique conditions within nurseries and to individual species and seedlots, (2) identifying and manipulating critical factors that most affect planting stock quality, (3) developing an effective system to evaluate planting stock quality and predict field performance, (4) developing planting stock and site preparation prescriptions for individual sites, and (5) developing computer models for the entire reforestation process.

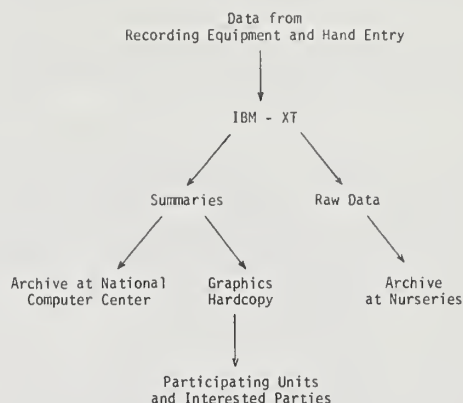
Some of the latest developments in reforestation science illustrate these points. There is a trend towards specific nursery culture of individual seedlots. Jenkinson (1980) has developed time windows for lifting several major timber species and specific seed sources at individual nurseries. Lifting seedlings outside these windows results in reduced survival and growth, and in the worst case, plantation failure. The Weyerhaeuser Company³ has led the way in growing seedlings by family (seed collected from a clone in a seed orchard), observing growth response to cultural treatments, and grouping families with similar growth into "response groups". Cultural treatments are then tailored to each "response group" to grow seedlings to desired specifications. This increasing sophistication brings increasing complexity and the need for more detailed record keeping, a task that computers can help us with nicely.

PARTICIPANTS AND ORGANIZATION

All 11 Forest Service nurseries are participating in the program. The nurseries are the center of RIP and the principal benefactors. The initial level of commitment at each nursery is to monitor three successive crops of planting stock of two seedlots of one species, and to establish two field plots on different sites.

³Personal communication with Dr. William C. Carlson, Tree Physiologist, Weyerhaeuser Co., Southern Forestry Center, Hot Springs, AR 71902.

The following organizational structure was developed for RIP in order to maintain communication and continuity:



A national steering committee monitors the overall program and modifies it as necessary. The program coordinator facilitates installation of the monitoring system, and implementation of data collection, summarization, and archival. A scientific analysis team (SAT) was created to select appropriate seedling measurement equipment and techniques, develop data collection and analysis procedures, and provide feedback and recommendations to individual nurseries. The team will evaluate the data from a research perspective and identify specific problem areas that need additional research.

Pathologists from the participating Regions will conduct pathogen and mycorrhizae analyses. National Forests and Ranger Districts interested in participating in the outplanting phase were identified before specific seed sources were selected for monitoring. The program has also arranged for a local research scientist to provide guidance for each nursery, a technician available by phone to provide support and spare parts for instrumentation problems, a software developer to prepare specialized methods to collect, summarize, graph, and archive RIP's data, and a technician to help with data processing.

EXPECTED BENEFITS

Benefits will increase each year as we monitor new seedlots, encounter different weather conditions, modify cultural practices, and accumulate information on field performance. Expected short- and long-term benefits are as follows:

Short-term (1 to 5 years)

1. Installation and implementation of state-of-the-art equipment and methods at the nurseries to monitor weather, culture, growth, quality, handling, and field variables, and efficiently summarize and retrieve the data on a computerized database at each nursery.

2. Development of a standardized system for collecting and analyzing nursery data to facilitate interchange of information and technology among nurseries, research units, and National Forests.
3. Increased awareness of seedling biology through tracking of seedling performance from seed to site.
4. Identification of stages in stock production, handling, shipping, and planting where quality is lost, so that nursery managers, foresters, and researchers can focus their efforts on the most critical areas. Some immediate improvement in reforestation success is expected from recognizing and correcting conspicuous problems.
5. Improved communications between nursery managers, field foresters, and researchers, eventually developing feedback linkages between these groups based on common goals.
6. Improved cultural and handling methods in the nursery by utilizing the database to aid decisions on when to perform certain practices, and to document the effects on seedling quality and performance.

Long-term (5 years and longer)

1. Significantly increased and more consistent tree survival and growth after outplanting, with fewer failures and replants, and lower reforestation costs. We should see increased efficiency through the entire reforestation process.
2. Development of specific cultural regimes to match seedlots and seedling characteristics to individual sites, thus utilizing the full potential of each site.
3. Improved nursery practices and knowledge of the relations between stock quality, site conditions, and field performance will improve our ability to predict tree survival and growth on a variety of sites and optimize the cost of stock production.
4. Development of a flexible quality control program for individual nurseries that can be continually refined. Seedling production will gradually shift from an art to a science, enabling nursery managers to manipulate numerous variables and consistently grow seedlings to target specifications.

ESTABLISHMENT OF NURSERY PLOTS

Each nursery is monitoring two different seedlots of at least one of the major species that it produces; five western nurseries are monitoring ponderosa pine, four western nurseries are monitoring Douglas-fir, one northern nursery is monitoring red pine, and one southern nursery

is monitoring both loblolly and longleaf pines. Ten nurseries made their initial sowings in 1986, and one nursery began this year.

The same seedlots of each species will be sown for 3 consecutive years so that they will be grown under a variety of weather conditions. Standard cultural practices will be used in the 100 feet of seedbed that will be sown for each seedlot and year. All the sowings will be clustered as close together as possible so that they are in similar soil and subject to similar weather conditions.

ENVIRONMENTAL MEASUREMENTS

Electronic recording weather stations are the heart of the environmental monitoring phase of RIP. One station is located on a permanent site at each nursery to collect baseline weather data. A second station is located near the test seedbeds so that sensors can monitor the weather and soil conditions to which the seedlings are actually exposed. Conditions measured are: air temperature at 1.5 m above ground and at the seedling canopy level (20 cm), relative humidity, precipitation and irrigation, wind speed and direction, incoming radiant energy and photosynthetically active radiation, soil surface temperature, and soil temperature and moisture in the seedling rooting zone. The recorder scans the sensors every 5 minutes and records the hourly maximum, minimum, and average temperatures; average humidity, radiation, and wind direction; average and maximum wind speed; and total precipitation or irrigation.

One-time measurements of soil physical characteristics were made in the test beds, and periodic measurements will be made of soil fertility, pathogen levels, and quality of irrigation and runoff water.

Environmental conditions that the seedlings are subjected to during lifting, processing, shipping, and planting will be carefully monitored. This will include factors such as root exposure time; temperatures during grading, storage, and shipping; and number of times the seedlings are handled. Temperatures during storage and shipping will be measured by another recording device, a Datapod⁴, that will be placed inside packing bags to record temperature hourly until the seedlings are removed from the bags for planting.

These environmental and history data will be used in graphics, in correlations with seedling growth in the nursery, and in interpretations of observed responses to culture.

⁴The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

CULTURAL PRACTICES

All cultural activities performed on the test seedlots will be documented by date and specific treatment. Any errors and unusual occurrences will be noted. Cultural practices include seed stratification, sowing, mulching, thinning, weeding, fertilization, irrigation, pesticide application, shoot and root pruning, and wrenching. No experimental treatments will be applied to the monitored seedbeds, but if any practice is changed nursery-wide during the program, the modified practice will also be instituted in the RIP seedbeds. This information will be used primarily for interpreting results rather than for making specific correlations with growth and performance.

SEEDLING MEASUREMENTS

Despite all the high-tech gadgetry, seedlings are the main focus of the program. We will examine them outside and in, i.e. morphologically and physiologically, and correlate their development, growth, and condition with (1) nursery environment and culture, and (2) field performance.

Monitoring will begin with establishment of history plots at time of sowing to determine germination rates and plantable seedlings as a percent of seeds sown. Random samples of seedlings in the seedbeds will be repeatedly measured to determine height and diameter growth, bud activity, and foliage color; and separate samples will be destructively measured to obtain root growth. We will monitor plant moisture stress during dormancy induction and mineral nutrient status in the fall when the seedlings have stopped growing.

Several measurements and tests will be done when seedlings are lifted: morphological (external) characteristics will be measured -- height, stem diameter, bud length, dry weight, and foliage color; and physiological (internal) conditions will be assessed by several tests -- mineral nutrient status, carbohydrate reserves, root growth potential, cold hardiness, and stress resistance.

Carbohydrate and mineral nutrient analyses require sophisticated equipment and will be done by private or university laboratories. The root growth potential, cold hardiness, and stress tests, however, will be done at the nurseries. This will be more economical, and the seedlings will not be subjected to storage and shipping that might alter their physiology. The main reason for doing the tests on site, however, is to give nursery personnel greater familiarity with the specialized measurements and tests of planting stock quality.

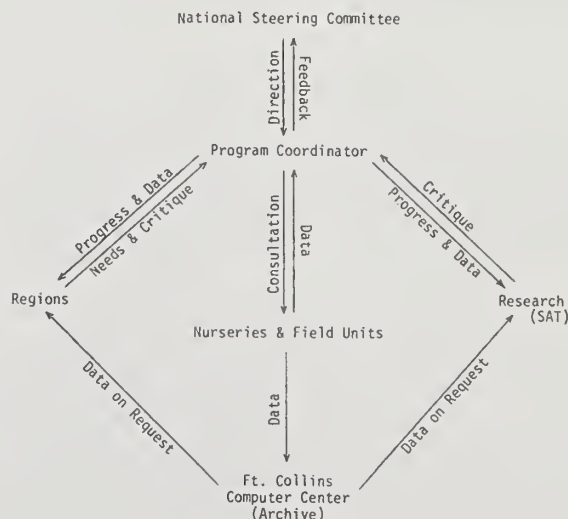
ESTABLISHMENT OF FOREST PLOTS

The payoff is, of course, field performance of the seedlings. It makes no sense to grow high quality seedlings if they are going to fizzle after outplanting, or disappear into the unknown. Therefore, we have asked various Forest Service Ranger Districts to establish and monitor test plantations. Planting stock from each nursery will be outplanted on two forest sites; each will have an electronic weather station identical to those used at the nursery. The sites will be partially planted in each of 3 consecutive years. Depending on the compatibility of the monitored seedlots with the seed zone of each forest site, some test plantations will be planted with both seedlots and others will have only one. Only 200 seedlings per seedlot will be planted and tracked per site, so it will not be a heavy workload. Site preparation will be the biggest problem on many sites because the program requires that approximately one-third of each site be planted in each of 3 consecutive years, but with site conditions as similar as possible. We will work individually with each National Forest to develop a planting plan that is operationally feasible, statistically valid, and consistent with RIP plans and objectives.

As with the nursery phase, environmental conditions, handling, seedling characteristics, and seedling performance on the field plots will be recorded for later analyses and correlations. We are working with the National Forests this year to make sure preparations are made for installing forest plots during the 1988 planting season.

DATA HANDLING AND ANALYSIS

Data collection and analysis are critical parts of RIP. The general plan for data flow is as follows:



Each nursery was provided with a micro-computer, electronic weather stations and data reader, datapods and reader, a portable data collector, and software to receive the transmitted data, automatically summarize it, and archive it.

Weather data are stored in a removable memory pack that holds 32,000 bits of information (64 K packs are now available). The packs are changed once a month. A full pack is plugged into a special reader that transmits the data to a microcomputer where a communications program captures it and stores it as an ASCII file. The pack is then erased and reused. The same scheme is used to retrieve package temperature data stored in the Datapods. The scheme designed for the portable data collector to collect seedling data and transmit it to the computer for processing is covered in more detail in a separate paper (Rietveld and Ryker 1988).

ASCII files containing the data are imported into preformatted spreadsheets where standardized data summaries and graphs are automatically generated through the use of macros. Graphs of weather data show monthly summaries of: incoming radiant energy, photosynthetically active radiation, precipitation, percent relative humidity, air temperature at 1.5 m, air temperature at 20 cm, wind speed, wind direction, soil surface temperature, soil temperature at 15 cm, and soil moisture at 15 cm. Graphs of seedling data are generated showing: seed germination, height growth, caliper growth, root growth, and bud activity, all in relation to time, air temperatures, soil temperatures, soil moisture, and solar radiation. Parameters such as growing degree days, chilling hours, and potential evapotranspiration are also calculated. Raw and summarized weather and seedling data from the nurseries and forest sites are archived at the nursery, and summarized data are archived at the National Computer Center at Fort Collins, CO, for safekeeping and sharing with approved interested parties.

INTERPRETATION OF DATA

Nursery managers can manipulate the data and generate other summaries and graphs as they wish. Such information will be useful in planning and evaluating day-to-day nursery operations and making decisions, as well as building a strong database for continuing quality control.

The data will also be evaluated by RIP's scientific analysis team. Because RIP is not a controlled research experiment, the opportunities to apply statistical analyses will be limited. Initially, the team will be restricted to making inferences based only on observations; after data are collected for three crops of planting stock (fall 1990), it will be possible to apply some limited statistical analyses. The general types of comparisons that will be made are as follows:

<u>Nursery</u>		<u>Nursery</u>
Weather		Seedling growth
History	<u>vs</u>	Seedling morphology
Culture		Seedling physiology

<u>Nursery</u>		<u>Field</u>
Seedling morphology		Seedling cond. on arrival
Seedling physiology	<u>vs</u>	Seedling surv. and growth
Processing & handling		

<u>Field</u>		<u>Field</u>
Site weather		Seedling surv. and growth
Site history	<u>vs</u>	
Pest problems		

Scientific analysis is expected to take the following progression:

Observations

1. Evaluate field performance -- if a seedlot does poorly at one site and not at the other site, look at site data; if a seedlot performs poorly on both sites, look at both site and seedling quality data.
2. Evaluate repeatedly measured variables (seedling height, caliper, root growth, foliage color, bud activity, plant moisture stress, root growth potential, and carbohydrate reserves) -- the only thing that can be done early in the program is to flag anything that looks suspect, since we don't know what constitutes a normal level for the variables at each nursery.
3. Contrast variables -- note differences in selected variables between seedlots, sites, and nurseries (for the same species). Graph selected variables for all nurseries growing the same species (ponderosa pine or Douglas-fir) to become familiar with basic nursery and seedlot differences.
4. Evaluate models and indices -- evaluate the usefulness of various models to relate weather variables to seedling growth and phenology (e.g. degree hours with seedling growth in the nursery, chilling units with cold hardiness, etc); and evaluate the ability of existing stock quality indices to predict seedling quality and performance.
5. Evaluate unusual events -- evaluate the effects of any disasters or any unusual weather events, contrasting nursery practices and field operations.

Statistical Analyses

1. Correlations -- by fall 1990, we will have first-season performance data on three crops of planting stock on each of two forest sites, giving a sample size of six for each seedlot. Correlation analysis of planting stock quality

variables (seedling height, caliper, dry weight, root growth potential, carbohydrate reserves, etc.) with performance variables (survival, height growth, caliper growth, etc.) will be barely possible because of the small sample size.

2. Regression analyses -- simple linear regression will be possible after we have data for three crops of stock. However, the real power of regression analysis cannot be realized until a sufficient range of data points is available, which will come with additional years of monitoring. To some extent, datasets can be expanded by including data from more than one seedlot and nursery (for the same species), but only if they satisfy certain tests for common regressions.
3. Develop standards and indices -- with sufficient data, application of single and multiple regression analyses will allow inferences of cause and effect relations in the nursery, between the nursery and the field, and in the field. Consistently significant relations may be used to develop indices that can be conveniently applied to predict response. In the process, we will evaluate, modify, and adapt existing indices and models for individual nurseries.

SUMMARY

The USDA Forest Service has undertaken an ambitious program to accelerate the transition of nursery management and reforestation from an art into a science. The goals of the Reforestation Improvement Program are to (1) supply

each nursery with state-of-the-art equipment and methods for recording weather, cultural, and seedling variables; (2) develop a monitoring system that links the nursery with the field and provides a system for feedback; and (3) develop a computerized database for each nursery that is easily accessed, is interactive with nursery management, and will eventually guide refinements in nursery culture and field operations. The real value of the database will grow in direct proportion with the quality and completeness of the data put in, and with time. There will be only a limited ability to extract information from the databases during the first few years; mostly we will benefit professionally by increasing the depth of our documentation and awareness. The real payoff comes with the accumulation of data over years. Eventually, with the assistance of research, we will develop culture/quality/performance relations for individual nurseries, establish appropriate stock standards, and greatly improve our ability to predict seedling performance on a variety of sites.

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Government vs Private Nurseries: The Competition Issue¹

Thomas D. Landis²

Abstract.--The issue of competition between government and private forest tree seedling nurseries has been politically sensitive in recent years. An analysis of both the different types of nurseries and seedling markets provided an information base. The question of competition in the forest nursery business can be analyzed in terms of seedling price and quality in the open and closed seedling markets. Although some degree of competition between government and private nurseries is inevitable, a number of positive approaches are presented which can overcome or prevent serious problems.

INTRODUCTION

Over the past decade there has been increasing concern over the issue of competition between government and private forest tree seedling nurseries. Advocates of nursery privatization have gone as far as introducing legislation both on the federal and state level to eliminate government-run nurseries. A recent informal survey was circulated to state forest nursery managers in the west to determine the extent of the government/private nursery competition problem. Survey responses indicated that all western nursery managers were concerned about the nursery competition issue, and that there was a serious problem in 29% of the states at the present time.

Actually, the government/private nursery controversy is not a new topic, but has surfaced several times in the past as evidenced by an editorial cartoon that appeared over 45 years ago (Figure 1). This cartoon was generated by the introduction of legislation that proposed the abolishment of the California State Tree Nursery at Davis. Apparently, the newspaper editors considered closing the state nursery a foolhardy proposition.

Responding to this widespread concern, the organizational committee for the 1987 Intermountain Forest Nursery Association

meeting decided to explore the nursery competition topic. Rather than have formal presentations expressing divergent, and sometimes polarized, points of view, an informal format was designed that encouraged communication and discussion. The facilitated small-group discussions generated a



Figure 1.--The government/private nursery controversy as depicted in the Sacramento Bee, April 4, 1941 (courtesy of G.A. Ahlstrom)

¹Paper presented at the Intermountain Forest Nursery Association meeting, Oklahoma City, Oklahoma. August 10-14, 1987

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comprehensive list of ways in which all forest seedling nurseries can work together to resolve, and possibly prevent, confrontation. This article was written to serve as an introduction to these small-group discussions.

The purpose of this article is to provide perspective on the government/private nursery controversy, which will hopefully lead to an increased understanding of the issues involved and some mutually acceptable solutions. Before we can analyze the government/private nursery issue, however, both the types of nurseries and the types of markets in the forest tree seedling business must be defined.

TYPES OF FOREST NURSERIES

Nurseries that grow woody plant seedlings can be organized into four classes:

1. Federal nurseries - these government nurseries, such as those operated by the USDA-Forest Service or USDI-Bureau of Indian Affairs, were established to produce seedlings for government forest lands. Most are prohibited from directly selling seedlings to other forest land holders or on the ornamental seedling market.

2. State nurseries - nurseries operated by state governments produce seedlings for a wider range of markets, including state forest lands, but also sell seedlings for conservation purposes on private forest lands. They are generally prohibited from selling seedlings for ornamental purposes.

3. Industrial nurseries - some of the larger forest industries have nurseries which produce seedlings for their own lands but also sell seedlings on the open market, including ornamental sales.

4. Private nurseries - these nurseries are operated by private individuals or corporations and sell seedlings for all purposes in any market.

TYPES OF MARKETS FOR FOREST TREE SEEDLINGS

There are two types of markets in the forest nursery business:

1. Open markets - seedlings can be purchased without restriction from any supplier. The open market consists of both large and small landowners who purchase seedlings from state, industrial, or private nurseries for a variety of conservation planting purposes.

2. Closed markets - customers are obliged

to purchase their seedlings from one supplier. Examples of closed markets can be found in both the government and private sectors. Tree seedlings for most federal forest lands are traditionally purchased from an associated government forest nursery. Some timber companies have also developed nurseries to produce seedlings for their own lands.

Another related, yet slightly different, market for woody plant seedlings is the ornamental seedling market which consists of seedlings sold for landscaping rather than conservation purposes.

DEFINING AND EXAMINING THE COMPETITION ISSUE

According to Webster's Dictionary, competition is defined as "the effort of two or more parties acting independently to secure the business of a third party by offering the most favorable terms". The question of competition, therefore, hinges on the phrase "most favorable terms" which, in the tree seedling nursery business, breaks down into 2 components: price and quality. These two factors can be analyzed in both the open and closed seedling markets:

The Pricing Issue in the Open Market

Most private and forest industry nurseries set their seedling prices based on demand in the open seedling market. There are basically two pricing structures in the open market: "spot market" and "contract". Spot market prices are established near the end of the crop rotation and are dependent on the traditional economic forces of supply and demand. Contract seedling prices are set at the time of contract award, before the seed is even sown, and are controlled by the terms of the specific contract. Most smaller landowners purchase their seedlings at the spot market price, whereas larger landowners and government nursery organizations normally purchase open market seedlings by contract.

Many state government nurseries have traditionally kept their seedling prices low to stimulate tree planting for conservation purposes. However admirable this pricing policy may be, it actually fuels competition because it keeps seedling prices below the open market value. Private nursery managers have a valid case when they contend that these artificially-low priced seedlings may lure potential customers away from their nurseries. One solution to the price issue is to set state nursery prices higher than private sources such as is being done by the California Division of Forestry. Using the dictionary definition, competition between state government and private nurseries would be eliminated under this pricing policy.

The Quality Issue in the Open Market

Although there has been much discussion and interest about seedling quality, this attribute remains an elusive property. Much research has been done on this subject, but there is still no standard definition or procedure for determining seedling quality.

Seedling quality is also variable from region to region. Because of vast differences in outplanting site conditions and in the genetic constitution of a seedling, an acceptable seedling from one geographical area may not survive in another. This is often due to the fact that seedlings adapted to lower elevations and milder climates are less cold-hardy than local species and can be damaged, or even killed, when planted in areas with harsher winters.

The use of source-identified, locally-adapted seedlings is absolutely essential in conservation plantings to insure that the seedlings will survive and grow after outplanting. The use of source-identified seed is well supported in the scientific literature although it is conveniently overlooked in some unprofessional nursery transactions. The question of whether locally-grown seedlings are better adapted to local planting sites is not as clear, but this practice has been traditionally emphasized by foresters in climatically-diverse areas like the Intermountain West. This "source-identified, locally-adapted" concept is critical in the forest nursery industry because the general public might be tempted to buy tree seedlings based on general appearance and price rather than quality.

The need for source-identified, locally-adapted stock is not as critical to many ornamental tree seedling growers because they deal with "cultivars" that are selected for foliage color or some other ornamental trait. Because they are planted in landscape situations where environmental stresses are minimal, cultivars can be produced by many different nurseries and are normally shipped over wide geographical areas.

Seedling quality is also a function of what happens to a seedling after it is harvested from the nursery. Many nurseries can grow reasonably healthy seedlings, but are not equipped to properly handle seedlings through the storage and distribution phase. Most larger forest nurseries in the west, both government and private, have well-designed seedling storage facilities and handling procedures. In some states with smaller seedling programs, however, government nurseries are often the only ones who have properly designed seedling storage and delivery systems - facilities like refrigerated storage and distribution vehicles that take seedlings out to the customer (e.g. "Trees on Wheels"

programs run by several western state forestry organizations).

Seedling Price and Quality in Closed Markets

Many nurseries that produce seedlings for their own use generally set prices based on production costs, rather than open market value. The price of federal government nursery seedlings is annually computed based on the cost of production, and therefore seedling prices reflect both variable costs like fertilizer and fixed costs such as machinery depreciation. In the past, because federal nurseries sold seedlings to the closed government market, the question of price competition with private nurseries was somewhat irrelevant. Now that private nurseries are producing contract seedlings for federal forest lands, however, the price issue becomes more meaningful and competition is possible.

One of the most important issues concerning the future of government seedling contracts with private nurseries revolves around the issue of seedling quality: the proven ability of private nurseries to supply quality seedlings on a sustained basis.

1. Proven ability - Many private nurseries have shown that they have the ability to produce quality forest tree seedlings, although a few nurseries with first-time contracts have not performed satisfactorily. Established nurseries that have demonstrated a good seedling production record, however, can expect to continue to receive government contracts.

2. Quality seedlings - Although some private nurseries have shown that they can produce good quality seedlings, government foresters have had some serious problems with private nursery contracts. Many of these problems have centered around contract seedling specifications: one of the relevant questions here is whether anyone can really write contract specifications that define something as complex and controversial as a "quality seedling".

There is also a tendency among many government contracting officers to think of seedlings as inanimate production units - "widgets". These non-biologists mistakenly think that quality tree seedlings are like any other contract item and can be routinely produced by anyone with the proper equipment. On the contrary, the ability to consistently produce a high-quality forest tree seedling crop requires technical expertise and cultural ability seasoned by experience, in addition to a suitable nursery facility.

The quality issue is not restricted to government contracts with private nurseries. Government nurseries also have problems with seedling quality from time to time, yet government foresters are often discouraged from purchasing seedlings from other sources.

3. Sustained basis - This issue is a "catch-22" and must eventually be resolved over time. Unfortunately, many government agencies only issue single-year seedling growing contracts and award them to the lowest bidder. Individual private nurseries have no way to be certain that they will have part of the government seedling market from year to year. Because of this ephemeral demand, many private nurseries have no way to prove that they can fulfill government seedling needs on a sustained basis.

The federal government has been purchasing more seedlings from private nurseries in recent years. As an example of this changing policy, Region 6 of the USDA-Forest Service (Oregon and Washington) has gradually increased its contracting requests for privately-produced tree seedlings. The number of private nurseries with Region 6 seedling production contracts has risen from 6 in 1984 to 10 in 1987, and the percentage of the total seedling orders filled by private nursery contracts has increased from 8 to 14% over the same time period.

CONCLUSION: SOLUTION THROUGH COOPERATION

The solution to the problem of government/private nursery competition must eventually be resolved through the cooperative efforts of all the parties involved. As is true in animal ecology, competition between two different organisms rarely leads to direct conflict, but rather to some socially-acceptable modification in the behaviour of each individual.

True to this ecological adage, a spirit of cooperation was evident in the small-group discussions during the government/private nursery session at this meeting. The opening statements of many participants reflected divergent viewpoints but, as they heard the positions of other group members, traditional barriers began to vanish. Two of the most significant observations to come out of these discussions were:

1. The government/private nursery competition issue is much more complex than most people originally thought. As is often the case, there are no simple solutions and increased communication between all concerned

parties is necessary to increase mutual understanding.

2. The situation varies considerably from one region of the country to another. What is true in the Pacific Northwest does not necessarily apply to the Great Plains or the South. Because of this regional variation, the problem should be treated on a local, rather than a national, basis.

As a product of these enlightening discussions, each group developed a positive list of ways in which all nursery managers can cooperate and resolve potential conflicts in the future (details of this exercise are reported in Session Two of the following article). Some of the more noteworthy ideas were:

1. Establish regional nursery advisory boards composed of representatives from both the public and private sector. The activities of these advisory boards would include planning and coordination, establishment of seedling quality standards, and conflict prevention.

2. Stimulate better communication between all types of nurseries to minimize potential conflicts and take advantage of opportunities to cooperate. This could include regular visits to other nurseries, and participation in local nursery associations.

3. Promote use of private nurseries for government seedling procurement, not only for excess needs, but as part of the annual program.

4. Each government nursery should develop a formal nursery policy that spells out their operating guidelines and how they relate to private sector nurseries with respect to potentially harmful practices like seedling marketing and surplus seedling sales.

The author would like to express his appreciation to Steve Hee of Weyerhaeuser Company, Jerry Ahlstrom of the California Department of Forestry, and to Dick Miller and Paul Forward of the USDA-Forest Service for providing valuable insight into this important issue and taking the time to review the manuscript.

Working Group Sessions on Communications and the Government/Private Nursery Issue¹

Kurtis L. Atkinson²

Abstract.--Facilitated working group sessions were held to develop lists of actions to improve communication and cooperation among nurseries in the Great Plains, and reduce the conflict between the government and private nursery sectors. These actions may be used as a starting point to improve working relationships between all nurseries.

Session I: Communications

A working-group exercise was held to identify areas in which forest nurseries could cooperate, communicate and share ideas. The attendees were divided randomly into four groups, and led through the process by a trained facilitator. It was structured as follows:

Purpose

Find ways to increase communication and cooperation between forest nurseries.

Desired Outcome

A list of opportunities for increased cooperation and communication between forest nursery organizations.

Process

Nominal Group Technique

Results

The results from the four groups follow. No attempt was made to consolidate these lists. The asterisks (*) denote items given a high priority by each group and were the only ones presented to the entire assembly.

Conclusion

It is hoped these results will stimulate interchange between nurseries, and perhaps serve as the basis for a formal method of exchanging and sharing information. The participants themselves must take the initiative to further develop these ideas into a workable method to take advantage of the opportunities which are evident.

Group I

- * 1. List of tree seed, seedlings and surpluses
- 2. Political issues facing nursery business
- 3. New cultural practices
- * 4. Share information on pesticides and new insects & diseases
- * 5. Co-op seed collection
- 6. Lists of salvage or replacement equipment
- 7. Tested modifications in nursery equipment
- 8. "Bugs & Cruds" problems and solutions
- 9. Interacting with locally operated nurseries
- 10. Quick response on first time problems

¹Results derived from working group sessions at the 1987 Intermountain Forest Nursery Assoc. meeting [Aug. 10-14, 1987, in Okla. City, Okla.].

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11. Use of by-products, recycling, etc.
- * 12. Improvements in safety
13. Bareroot precision sowing
14. Facilities that may be available (contract/otherwise)
15. Species list
- * 16. Nursery practices which enhance outplanting survival
17. Human resources available for consultation
18. Alternative labor sources /employment opportunities
19. New insect & disease information
20. Development of national grading standard
21. Seedling testing
22. Packing containers (type/cost)
23. Germinating problem species
24. Effective control of weeds
25. Improving customer relations
26. Odd species seed availability
- * 27. Improved seed and seedling storage
28. Good tiers (taers)
29. Bareroot vs. containers
30. Re-cycling to save costs; tubes, boxes, etc.
31. List of suppliers, costs, bulk ordering
32. Cooperative studies of cultural practices
33. Results of seedbed densities
34. Sample contracts
- * 35. List of current nursery studies
36. Grading & handling of bareroot stock
37. Outplantings, contracts, contractors, equipment
38. Bookkeeping practices
39. Research & observation of new methodology
40. University resources (testing person power)
- * 41. Innovative ways for seed stratification
42. Accurate forecasting needs & wants (market data)

Group II

- * 1. Surplus/shortages of seedlings & seed
2. Quarterly recaps of productivity and activities; a procedure for dissemination
- * 3. Educational program, i.e., training of staff, foremen, & nursery personnel (management, computers, etc.)
- * 4. Seed collection, seed source i.d., purchasing seed, cooperation
5. Pooling of resources to promote more intensive tree improvement program between states
6. Incentives to increase productiveness of seasonal labor

7. Consolidated purchasing of materials and services
8. Interagency, state and regional cooperation on I&E
- * 9. Mechanical innovations/developments
10. Sharing of equipment and supplies in the event of breakdowns
11. Cooperative growing of seedlings
12. Personnel needs
13. Better feedback on plant material success from the field
- * 14. Information system that is applicable to nursery management and administration (principally PC software)
15. Exchanging expertise in specialized area
16. Equipment specification and performance
17. Vendor listing by categories and region
18. Join together to market products
19. Provide cooperative R&D on problems and opportunities that are common to nurseries
- * 20. Information exchange of specific cultural situations and problem solving, including: pesticides, pests, nutrients, soil/pesticide interactions, innovations, seed handling, collection, processing, etc.

Group III

- * 1. Day to day cultural and operational tips
2. Record keeping
3. Harvesting techniques
- * 4. Who's doing what (research, etc., names of contacts)
- * 5. Listing of nurseries, species, capacities, addresses, phone numbers, etc.
- * 6. Equipment technology & shared equipment performance information
- * 7. New laws relating to chemical use, personnel management, environmental constraints (in understandable form - do's & don'ts)
- * 8. Promotional techniques & materials
9. R.I.P. information sharing
- * 10. What's and How's in connection with herbicide use
- * 11. Inventory: surpluses, shortages & prices
12. Surplus supplies inventory
13. Relate seedling quality to field performance
- * 14. Problem alert system
15. Job openings
16. Seed availability - price
17. Techniques of inventory control, sales, and delivery management

- * 18. Software needs & availability
- 19. Methods of packing
- 20. Cost reduction techniques
- 21. Evaluation of seed sources for different products

Group IV

- 1. Success/failure in weed management, herbicides, why?
- 2. Insect alerts, aphids/hoppers
- * 3. What expertise do others have in specific areas?
- * 4. Software that others use such as storage & retrieval of cultural and production information
- 5. Training opportunities
- 6. Sharing, coordinating, interpreting data
- 7. Telecommunications network
- * 8. How inventories? Accuracy rates, costs, procedures?
- 9. Calibrating mechanical seed sowers, what accuracy experienced?
- 10. Combined inventories of spare parts
- * 11. What supplies in common and where acquired (boxes, chemicals, etc.) possible coordination of purchasing.
- 12. Surplus seed and seedlings
- 13. Surplus equipment
- 14. Available services (tissue analysis, diagnosis, etc.)
- 15. Seed sources (especially hardwoods)
- 16. Comparing germination data
- 17. Coordinating equipment development
- 18. Coordinating job opportunities
- 19. Bulletin board service with telecommunications
- 20. Seedling packing containers and medium
- * 21. Success or failure of plantations
- 22. What policies or guidelines do others use? (size of seedlings, complaints, many more)
- * 23. Success/failure - pest management, fungicides, fumigants, insecticides, why?
- 24. New materials available for pest control
- * 25. What criteria others use to determine seedling quality? Equipment used? Which best to predict field survival?
- 26. Comparing clean seed yields
- * 27. Ideas about formal research and informal trials underway at other nurseries, results.
- * 28. Availability and use of climatic data to plan planting schedules and make yield predictions.
- * 29. Successes/failures in soils management (pH, fertilization, etc.)
- 30. Storage temperatures by species.

- * 31. What species are others growing? What cultural practices?
- * 32. Planting methods, methods of reforestation, equipment, etc.
- 33. Invite a friend to lunch and share information.
- 34. Tonight is ladies night in the bar.

Session II:

Government vs Private Nurseries

A second working-group exercise was held to address the government/private nursery issue. The attendees were divided randomly into three groups, each with a trained facilitator and recorder who coordinated the process. It was structured as follows:

Issue

Private sector concerns about competition from publicly operated nurseries.

Purpose

1. Stimulate participants' minds about things they or their organization can do to help reduce concerns about this issue.

2. Document the suggestions of this group of experts, close to the issue, for use by various organizations who may be studying the issue.

Process

Facilitated Discussion

Results

The results from the three groups follow. No attempt was made to prioritize the ideas within the groups, nor to consolidate the statements for the conference as a whole.

Conclusions

The result of this session will be provided to the National Association of State Foresters to use during their consideration of this issue. The participants should also take the initiative to further develop these ideas into a workable, cooperative and mutually agreeable plan of action.

GROUP 1

1. Artificially set seedling prices from government nurseries higher than private sector, on state by state basis.
2. States develop a policy statement related to public nursery activities, with private sector participation.
3. Contract with private nurseries to produce stock for use on public lands.
4. Establish a nursery advisory board, with representation from all sectors.
5. Assure selected (certified) seed sources are available to all growers.
6. Public education about the need for quality seed sources, species, quality of planting stock, etc.
7. Regional coordination of nursery policies, etc.
8. Assure private sector is included as an option during public agency technical assistance (CRP).
9. Establish basic standards of stock quality, seed sources, species selection.
10. Public and private sectors should target market areas.
11. Nursery Board act in conflict resolution.
12. Define, clarify and continue to evaluate the need for public nurseries.
13. Public nurseries become more involved in private associations (e.g., AAN, State Association, etc.)

GROUP 2

1. Public nurseries should develop marketing policies with input from private and public sectors.
2. Develop joint promotional/educational effort to encourage tree planting.
3. Develop nursery advisory boards by state/region involving all sectors - public (state & federal) and private.
4. Personal contact with private nurseries for the purpose of information exchange by field and nursery personnel.
5. Sponsor a public nursery inventory surplus list for distribution to local private nurseries for seedlings that are available for sale.
6. Public nurseries should charge their actual production costs (including costs of land and overhead).

7. Utilize private nurseries to provide flexibility rather than expand public nurseries (includes contracting special needs, trading stock, etc.)
8. Develop a positive medium for information/technology transfer promoting cooperative partnerships.
9. State/Federal Forester rep. should belong to State Nursery Assoc.

GROUP 3

1. Increase communication among all groups.
2. Share in each others planning process.
3. Increase supply contracts to private nurseries (state & federal).
4. Moth ball marginal state or federal nurseries.
5. When comparing quality and cost, use the same criteria and accounting procedures.
6. Establish regional advisory boards to address needs and impacts.
7. Moth ball or contract out low demand species.
8. Limit the programs eligible for discounted seedlings.
9. Sales from government nurseries to private nurseries.
10. Study competition issues in other industries. How do they resolve problems?
11. All public nursery managers join their state's nursery association.
12. Have people involved in harvest planning on advisory boards to help predict the future.
13. Separate state and federal issues when talking about alternatives. Separate conflicts/address separately.
14. Show and tell at public nurseries for private nursery managers.
15. Examine decentralized seedling procurement in the federal system.
16. Make sure advisory board members are knowledgeable.
17. Make sure spokesmen from private sector are expressing the majority opinion.
18. Standard grading for seedlings.
19. Develop an action plan.
20. Implement.

Minutes of the Annual Business Meeting

The meeting was called to order by Tom Landis at 8:30 A.M. on Friday, August 14.

Old business: The Proceedings of this meeting will again be published as a General Technical Report by the Rocky Mountain Forest and Range Experiment Station, with funds provided by State and Private Forestry, USDA-Forest Service. The last date for papers to be submitted for the Proceedings is October 1, 1987, and target date for publication is January 1, 1988. Send papers to Bob Hamre at the Research Station, or call Tom if you have questions.

New business: The 1988 Intermountain Forest Nursery Association meeting will be held in Vernon, B.C. on August 10-12, 1988. This will be a joint meeting of the Intermountain Nursery Association, the Western Forest Nursery Council, and The Forest Nursery Association of British Columbia. Ralph Huber of the B.C. Ministry of Forests is coordinating the meeting plans and an informational mailing should be

distributed this fall. Ralph can be contacted at 604-387-8942 for more information.

The 1989 Intermountain Forest Nursery Association meeting will tentatively be scheduled for either North or South Dakota. More information will be forthcoming as plans develop.

The Intermountain Forest Nursery Association is 27 years old! Marv Strachan, nursery manager emeritus and organizer of the first meeting, has volunteered to develop an archive for the association. He will be attempting to gather a complete set of past proceedings, and index them for easy reference. The end product will be a complete set of all Intermountain Forest Nursery Association Proceedings with a subject index. Tom Landis added that State and Private Forestry supports this project and will attempt to secure financing.

There was no further business, so the meeting was adjourned at 9:00 A.M.

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Rocky
Mountains



Southwest



Great
Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

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